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Factors related to rapid deceleration events among a large cohort of older drivers

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ABSTRACT

Studies over the past two decades have attempted to document and understand factors related to crashes involving older drivers to develop more effective countermeasures to reduce the frequency and severity of these crashes. Studies in which vehicle acceleration data can be recorded have begun to explore the relationship between rapid deceleration events (RDEs) and functional abilities among older drivers as a surrogate measure of unsafe driving. Recent naturalistic driving studies with older adults have found differing results using different thresholds to define an RDE. The present study examined the relationship among RDE rates, demographics, visual abilities, cognitive abilities, and driving comfort among a large cohort of older drivers, using two definitions of RDEs—longitudinal deceleration of 0.35 g or greater (RDE35) and longitudinal deceleration of 0.75 g or greater (RDE75). The study utilized objective driving, objective functioning, and reported driving comfort data from 2774 participants of the multi-site AAA Longitudinal Research on Aging Drivers (LongROAD) study. RDE rates for each threshold were calculated per 1000 miles driven. Multivariate regression models with backward elimination were developed to examine how outcome measures were related to RDE rates. Too few RDE75 events were found for meaningful analysis. RDE35 rates were significantly associated with several

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covariates. RDE35 rates were related to declining functional abilities, but many other factors also played a significant role in the rate of RDE35s among older drivers, diminishing the value of using RDE35 rates as a surrogate measure of driving safety. In addition, because the AAA LongROAD sample was relatively healthy and high functioning, other ability-related covariates may also be significantly related to RDE35s but the lack of variance in these measures in the current study prevented these effects from emerging.

1. Introduction

The average age of populations across most countries continues to increase (United Nations, 2017) and more drivers age 65 and older (older drivers) are holding licenses well into older adulthood (Sivak & Schoettle, 2012). With aging, comes a higher likelihood of declines in abilities needed for safe driving (Dickerson et al., 2017). During 2014 and 2015, there were 12,445 older drivers involved in fatal motor vehicle crashes in the United States (US, National Highway Traffic Safety Administration, NHTSA, 2016, 2017). In both years, these numbers accounted for about 13.4% of all drivers involved in fatal crashes. Tefft (2017) calculated crash involvement rates per miles driven in the US over these same years by age group and found that rates for both injury and fatal crashes decreased with increasing age up to age 60–69, and then increased for older age groups, with large increases found for drivers age 80 or older. Thus, despite the known self-regulation that occurs among many older drivers (see e.g., Molnar et al., 2013), crash rates based on driving exposure still show higher crash involvement for older drivers, although fragility may account for some of these differences in crash rates (e.g., Kent, Trowbridge, Lopez-Valdes, Ordoyo, & Segui-Gomez, 2009; Li, Braver, & Chen, 2003; Meuleners, Narding, Lee, & Legge, 2006).

A large number of studies over the past two decades have attempted to document and understand factors related to crashes involving older drivers to develop more effective countermeasures to reduce the frequency and severity of these crashes (see e.g., Braitman, Kirley, Ferguson, & Chaudhary, 2007; Clarke, Ward, Bartle, & Truman, 2010; Hakamies-Blomqvist, 1993; Ichikawa, Nakahara, & Taniguchi, 2015; Langford & Koppel, 2006; McGwin & Brown, 1999; Rakotonirainy, Steinhardt, Delhomme, Darvell, & Schramm, 2012). Recently, studies in which vehicle acceleration data were recorded explored the relationship between hard braking events (rapid deceleration events, RDEs) and safety-related outcome measures such as near crashes and declining functional abilities (Chevalier et al., 2017; Dingus et al., 2006; Fung, Wallace, Chan, Goubran, Porter, Marshall, & Knoefel, 2017; Keay et al., 2013; Zhao et al., 2012). For example, simulator studies of young and middle age drivers of light truck vehicles who make rapid decelerations showed that these events are predictive of rear-end crashes (see e.g., Harb, Radwan, Yan, & Abdel-Aty, 2007; Yan, Abdel-Aty, Radwan, Wang, & Chilakapati, 2008). Dingus et al. (2006) used RDEs as a proxy for near-crashes. In this study, the researchers used a longitudinal deceleration of 0.5 g or greater and confirmed these events as being near-crashes through a review of video data. A study of naturalistic driving among novice, teen drivers that examined RDEs (defined as longitudinal decelerations of 0.45 g or greater) found that these events were more frequent when teens were driving with teen passengers (Simons-Morton et al., 2009). Zhao et al. (2012) compared scores on the Driver Behavior Questionnaire (DBQ, Parker, West, Strading, & Manstead, 1995) and driving behavior, including a global measure of longitudinal/lateral/non-directional deceleration defined as 0.1 g or greater, among three age groups of drivers. These researchers found that among the older driver age group, there were significantly more RDEs among those with high "violation" scores on the DBQ as compared to those with low violation scores, indicating that older drivers who more often reported deliberately breaching legal and/or socially acceptable driving behaviors also had more rapid decelerations. A study in Israel (Musicant, Botzer, Laufwer, & Collet, 2018) analyzed physiological measures during on-road driving among a sample of middle age male drivers during two types of braking events: "non-intensive" (0.49 g or less) and "intensive" (0.5 g or greater). The study found significantly higher levels of physiological arousal during the intensive braking events, suggesting that RDE of 0.5 g or greater may be perceived by drivers as safety-critical maneuvers. Collectively, these studies show that RDEs can be related to driving safety.

There is good evidence that declines in functional abilities among older drivers are associated with poorer driving performance and increased crash risk (see e.g., Emerson et al., 2012; Dawson et al., 2010; Lacherez, Wood, Anstey, & Lord, 2014; Ott et al., 2013; Rapoport et al., 2013; Wood & Owsley, 2014). Two studies recently examined the relationships among functional abilities, other factors, and RDEs in naturalistic driving among cohorts of older drivers; they yielded distinctly different results, although they also used different thresholds for rapid deceleration (Keay et al., 2013; Chevalier et al., 2017). Chevalier et al. (2017) investigated 177 older drivers (age 74–94 years) over one year of driving and found that those with poorer contrast sensitivity and lower driving confidence had higher RDE rates (defined as longitudinal decelerations of 0.75 g or greater) and concluded that RDEs could be used as a surrogate safety measure among older drivers. Keay et al. (2013), on the other hand, examined 1425 older adults (age 67–87 years) over a five-day period of naturalistic driving and found that those with poorer visual, cognitive, and psychomotor function (measured by a number of objective tests) were less likely to perform RDEs and exhibited lower RDE rates (defined as longitudinal decelerations of 0.35 g or greater). These authors concluded that drivers who engaged in more RDEs tended to be more medically fit, suggesting that RDE rates among older drivers are not indicative of unsafe driving. These discrepant results may be related to the differences in cohort ages, the differing lengths of participation, or, most likely, the different thresholds used to define RDEs. A deceleration of 0.35 g would result from a vehicle braking from 40 mph to 0 mph in about 5 sec, whereas a 0.75 g would be achieved with this same change in velocity over about 2.4 sec.

The present study examined the relationship among RDE rates, demographics, functional abilities (visual, cognitive, and psychomotor), and driving comfort among a large cohort of older drivers, using two definitions of RDEs—longitudinal deceleration of approximately 0.35 g or greater (the value used by Keay et al., 2013) and longitudinal deceleration of approximately 0.75 g or greater (the value used by Chevalier et al., 2017). Specifically, the study assessed the following two hypotheses: (1) There will be higher RDE rates among those drivers who have poorer outcomes on tests of functional abilities and lower driving comfort; that is RDEs have value as a surrogate measure of driving safety; and (2) The higher RDE threshold of 0.75 g will be more strongly correlated with declining function and driving comfort than the 0.35 g RDE threshold.

2. Methods

The study utilized data from 2774 participants of the multi-site AAA Longitudinal Research on Aging Drivers (AAA LongROAD) study. The AAA LongROAD study was designed to explore several areas of older driver safety and mobility. Study participants were enrolled from areas in or near five cities in the US (Ann Arbor, MI; Baltimore, MD; Cooperstown, NY; Denver, CO; and San Diego, CA). AAA LongROAD data include self-reported health (i.e., mental, social, physical, and cognitive health, behaviors, conditions, and impairments and symptoms) and objectively measured health, functional abilities (i.e., cognition, psychomotor skills, and perception), and driving behaviors; medical record information; and driving violation and crash records. All study protocols were approved by each site's Institutional Review Board. Further details of the data collection system, study methods, and power analysis to determine sample size can be found elsewhere (Li et al., 2017). The present study utilized objective visual and cognitive data collected at baseline, questionnaire data collected at baseline, and global positioning system (GPS) data collected over one year of driving after baseline.

AAA LongROAD participants were recruited through primary care clinics associated with the health system at each study site, and participants were paid up to $100 per year (depending on the site) for their involvement in the study. Participant inclusion criteria were: age 65–79 years; possession of a valid driver's license; driving at least once a week on average; no significant cognitive impairment as determined by a score ≥4 on the Six Item Screener (Callahan, Unverzagt, Hui, Perkins, & Hendrie, 2002) and medical record review; driving a single vehicle at least 80% of the time; driving a vehicle that was model year 1996 or newer; no plans to move out of the study area in the next five years; and resided in the study area for at least 10 months of the year. Eligible individuals were scheduled for an in-person baseline session during which they completed, among other tests, a set of visual and cognitive ability tests and a questionnaire on driving habits and comfort. Three aspects of visual ability were objectively measured: acuity (tumbling E test); contrast sensitivity (Pelli-Robson Test; Pelli, Robson, & Wilkins, 1988); and overall visuospatial perception ability (Motor Free Visual Perception Test, MVPT-3, Colarusso & Hammill, 2003). The following aspects of cognitive ability were measured: verbal fluency (Retrieval Fluency Test; Wallace & Herzog, 1995); executive function (Trail Making A and B; Army Individual Test Battery, 1944); visuospatial ability (Clock Drawing Test; Freund, Gravenstein, Ferris, Burke, & Shaheen, 2004); episodic/working memory (Immediate and Delayed Word Recall; Wallace & Herzog, 1995); and attention and psychomotor speed (Digit Symbol Substitution Test [DSST]; Wechsler, 1981). Simple and choice reaction times were also measured (Deary, Liewald, & Nissan, 2011). Driving comfort was measured through self-reported level of comfort on a 7-point scale with 1 being not at all comfortable and 7 being completely comfortable in 10 driving scenarios (Molnar et al., 2014): driving at night, making unprotected left turns, driving in bad weather, driving on busy roads, driving in unfamiliar areas, driving alone, driving at night in bad weather, driving in rush hour, driving on the freeway, and backing up.

Also at baseline, each participant's vehicle had a datalogger device installed in the on-board diagnostic (OBDII) port. The datalogger recorded GPS information whenever the vehicle ignition was turned on. The datalogger also used a cellular phone signal to automatically send data to the AAA LongROAD data center at the end of each trip. To determine that the participant was driving the vehicle, all drivers of the participant's vehicle carried a credit-card-sized beacon that broadcasted a unique coded signal that could be recorded along with the signal strength to a Bluetooth receiver on the datalogger. This information allowed us to determine the driver of the vehicle and remove any trips made by non-participants. RDEs were calculated from longitudinal acceleration derived from vehicle speed from the GPS data gathered at 1 Hz. Vehicle speed was smoothed using a simple moving average centered over a three second period (phase neutral). Smoothed speed was differentiated to derive a continuous estimate of the longitudinal vehicle acceleration. These longitudinal data were then searched for continuous periods of time when the measure was negative with a value greater than or equal to 3.5 m/s^2 (corresponding to 0.35 g deceleration) and greater than or equal to 7.5 m/s^2 (corresponding to 0.75 g deceleration). For each participant and each trip, counts of all RDEs with a peak value of either 0.35 g or more or 0.75 g or more and a starting speed greater than 4.47 m/s (10 mph), regardless of the event duration, were recorded. This method for determining RDEs based on GPS data sampled at 1 hz differed from both the Chevalier et al. (2017) and Keay et al. (2013) studies that used accelerometers that gathered data at either 10 hz or 32 hz. As such, the method used in the present study was less sensitive for determining RDEs than the methods used in the previous studies.

Prior to beginning the study, the research team conducted an extensive validation study that compared the AAA LongROAD datalogger data to data collected from a high-fidelity data acquisition system installed in the same vehicle. Data from the two systems were compared for GPS coordinates, acceleration, derived-acceleration, and speed. The analyses showed high agreement between the two systems for all variables.

3. Analysis

Each participant's first 12 months of full driving data were identified and monthly averages of the number of RDEs and the number of miles driven were calculated across all 12 months. An RDE rate for each threshold was calculated per 1000 miles driven using both of these monthly averages.

Multivariate regression models with backward elimination were developed to examine how outcome measures were related to RDE rates. Separate models were conducted for RDEs defined with a cutoff of 0.35 g or greater (RDE35) and 0.75 g or greater (RDE75). A negative binomial regression approach was used for RDE35 because rapid deceleration events represent a count outcome and the distribution of RDE35 rates was over-dispersed. The regression model included an offset of the logarithm of the number of miles driven. A zero-inflated Poisson regression approach was used for RDE75 because the distribution of RDE75 rates were not over-or under-dispersed and 98% of the participants had zero RDEs at this threshold. The Wald test with significance levels set at $p < 0.05$ was used to determine elimination/retention in all regression models. The regression models were controlled for study site and seven objective driving measures selected from 11 possible objective driving measures. Prior to the first regression analysis, a Spearman correlation analysis was conducted to examine the relationship between RDE rates and the same set of objective measures to identify potential covariates significantly correlated with RDE rates and to flag potential covariates that were too highly correlated with one another. As a result, all regression models were adjusted for the number of trip chains (a trip chain included all trips occurring between the time the participant left home and returned home), percent of trips at night, percent of trips during AM peak, percent of trips during PM peak, percent of trips on high speed roads, percent of trips within 15 miles of home, and number of speeding events (driving 80 mph or greater for at least 8 sec). Further definition of these measures can be found in Molnar et al. (2013, 2018).

For the physical functioning measures, there were more than 20 objective cognitive/visual measures considered for inclusion in the analysis. Due to the large number of potential predictor measures, univariate models were conducted first to determine which predictor measures to include in the multivariate model. The univariate models were controlled for the same measures used to control the multivariate models. The significant predictor measures from the univariate models were included in the multivariate regression analyses.

For the analyses of driving comfort measures, separate modeling with backward elimination was conducted for the 10 individual driving comfort measures and a composite comfort measure that combined perceived driving comfort in the 10 driving situations. The measures that significantly predicted RDE from the modeling for demographics and physical functioning were also included as predictors in the models for driving comfort. All analyses were conducted using SAS Version 9.4 (SAS Institute Inc., Cary, NC).

4. Results

4.1. RDE counts and rates

Over the 12-month period, 2774 participants drove a total of 26,169,650 miles, with an average of 9434 ± 5308 miles per participant. During this period, a total of 124,738 RDE35s (range per participant = 0–678) and 124 RDE75s (range per participant = 0–25) were recorded. Nearly all participants (99.6 percent) had at least one RDE35 but only 2 percent of participants had an RDE75. The RDE rates per 1000 miles were: RDE35, 5.3 ± 6.2 (range = 0–91); and RDE75, 0.005 ± 0.06, (range = 0–2.7).

4.2. Demographics

Participants were 53 percent female. The percentages of participants by age group were: 65–69 years (42 percent), 70–74 years (34 percent), and 75–79 years (24 percent). Reported education levels (n = 2765) were 28 percent with less than an undergraduate degree, 30 percent with an associate or bachelor's degree, and 42 percent with a graduate degree. Reported annual household income levels (n = 2677) were: less than $50,000 (26 percent); $50,000–$79,999 (25 percent); $80,000–$99,999 (15 percent); $100,000 or more (34 percent). RDE35 and RDE75 rates by demographics are shown in Table 1.

4.3. Visual/cognitive abilities

Because of differences in how the Tumbling E test was administered at one site, data from this site were not included in the analysis of visual acuity. Fig. 1 shows the distribution of visual acuity scores converted to logMAR scores (n = 2208). Note that a score of zero is average (20/20 from the Snellen scoring) and participants with scores equal to or greater than 0.3 are considered to have visual impairment (10.8 percent of the sample). Figs. 2–4 show the distribution of scores for contrast sensitivity (Fig. 2; Pelli-Robson), overall visual perception ability (Fig. 3; MVPT-3), and visuospatial skill (Fig. 4; Clock Drawing

Table 1
RDE35 and RDE75 Average Monthly Rates per 1000 Miles Driven by Demographics.

	n	RDE35		RDE75	
		Mean (SD)	Range	Mean (SD)	Range
Sex					
Male	1308	5.0 (5.6)	0–57.1	0.006 (0.09)	0–2.7
Female	1466	5.7 (6.6)	0–91.0	0.003 (0.03)	0–0.6
Age					
65–69 years	1158	5.4 (6.8)	0–91.0	0.007 (0.09)	0–2.7
70–74 years	953	5.2 (5.8)	0–52.4	0.003 (0.04)	0–0.8
75–79 years	663	5.4 (5.7)	0–41.7	0.003 (0.03)	0–0.6
Education					
Less than an undergraduate degree	781	5.4 (6.7)	0–91.0	0.100 (0.10)	0–2.7
Associate or bachelor's degree	834	5.6 (6.7)	0–58.6	0.002 (0.02)	0–0.4
Master/professional/doctoral degree	1150	5.1 (5.5)	0–57.1	0.004 (0.04)	0–0.8
Income					
Less than $50,000	703	5.9 (7.2)	0–91.0	0.009 (0.10)	0–2.7
$50,000 - $79,999	678	4.7 (5.9)	0–57.1	0.002 (0.02)	0–0.4
$80,000 - $99,999	398	4.9 (5.5)	0–52.4	0.002 (0.02)	0–0.3
$100,000 or more	898	5.5 (5.9)	0–58.6	0.005 (0.05)	0–0.8
Site					
CO	530	6.2 (6.1)	0–52.4	0.003 (0.03)	0–0.4
NY	566	2.8 (3.3)	0–34.9	0.005 (0.04)	0–0.6
MD	554	5.0 (5.0)	0–39.9	0.01 (0.10)	0–2.7
MI	569	5.0 (4.7)	0.1–35.4	0.001 (0.01)	0–0.2
CA	555	7.8 (9.2)	0–91.0	0.003 (0.02)	0–0.3

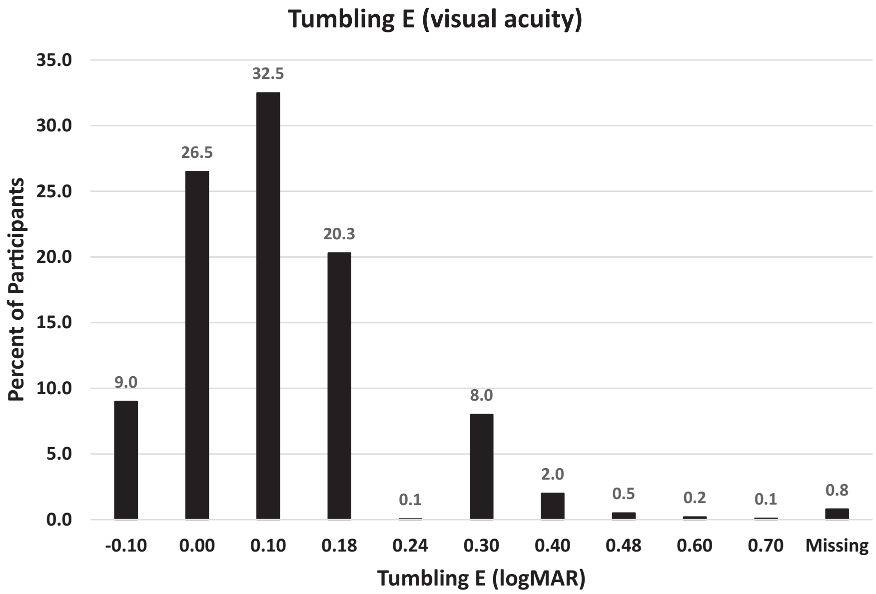

Fig. 1. Distribution of visual acuity scores as measured by the Tumbling E test.

Test; Freund et al., 2004), all with n = 2774. In all figures, higher scores indicate better functioning. The number of participants, overall means, confidence intervals, and ranges for each of the other cognitive measures are shown in Table 2.

4.4. Driving comfort

The overall means, standard deviations, number of participants for the 10 driving scenarios, and composite measure of driving comfort were: nighttime (n = 2771; 5.5 ± 1.4); left turns without left turn arrow (n = 2768; 6.1 ± 1.3); bad weather (n = 2767; 5.1 ± 1.5); busy roads (n = 2773; 6.0 ± 1.2); unfamiliar areas (n = 2766; 5.7 ± 1.2); alone (n = 2772; 6.7 ± 0.6); at night in bad weather (n = 2769; 4.8 ± 1.6); rush hour traffic (n = 2767; 5.7 ± 1.3); freeway (n = 2765; 6.3 ± 1.2); backing up (n = 2772; 6.2 ± 1.2); and composite (n = 2774; 5.8 ± 0.9). The range for each measure was 1–7.

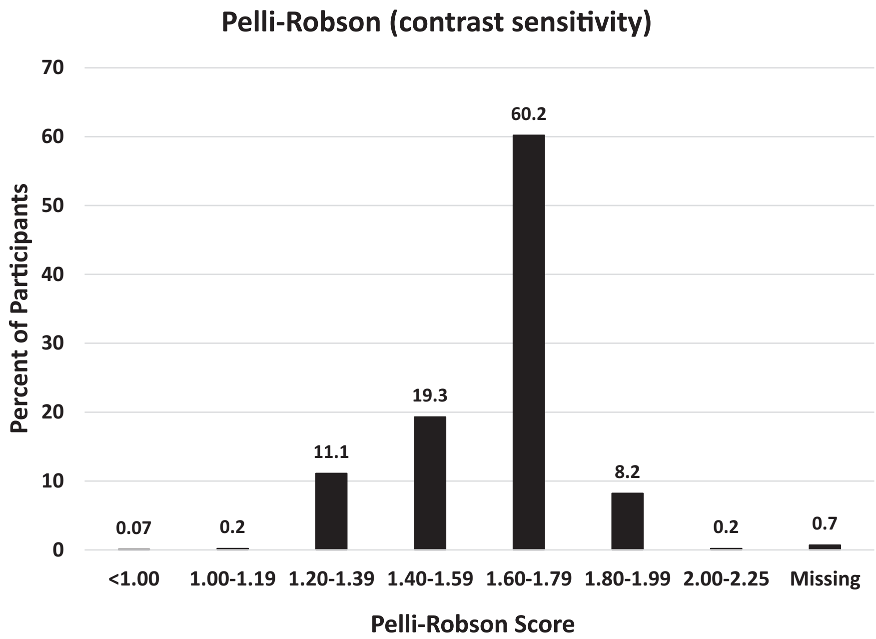

Fig. 2. Distribution of contrast sensitivity scores as measured by the Pelli Robson test.

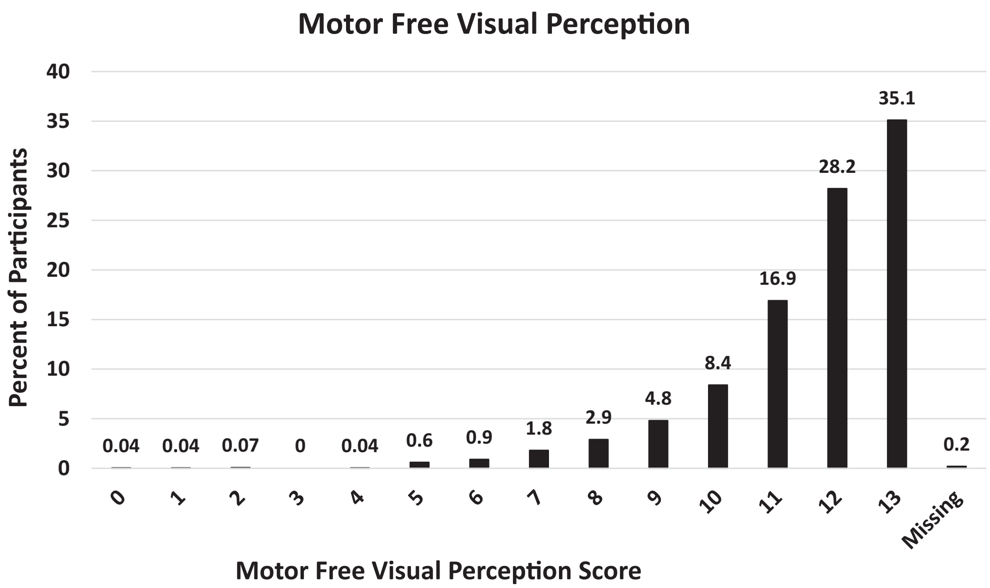

Fig. 3. Distribution of visuospatial perception ability scores as measured by the Motor Free Visual Perception test.

4.5. Multivariate regression modeling

Focusing first on the objective driving measures, percent of trips on high speed roads and percent of trips at night were eliminated in the initial steps of the multivariate negative binomial regression modeling for being non-significant. The modeling showed that number of trip chains, percent of trips during morning peak, percent of trips during afternoon peak, percent of trips <15 miles, and number of speeding events were significantly associated with RDE35 rates (Table 3). As shown in Table 4, the RDE35 rate decreased 5 percent for every unit increase in the number of trip chains; the RDE35 rate decreased 2 percent for every unit increase in the percent of trips during AM peak; the RDE35 rate increased 1 percent for every unit

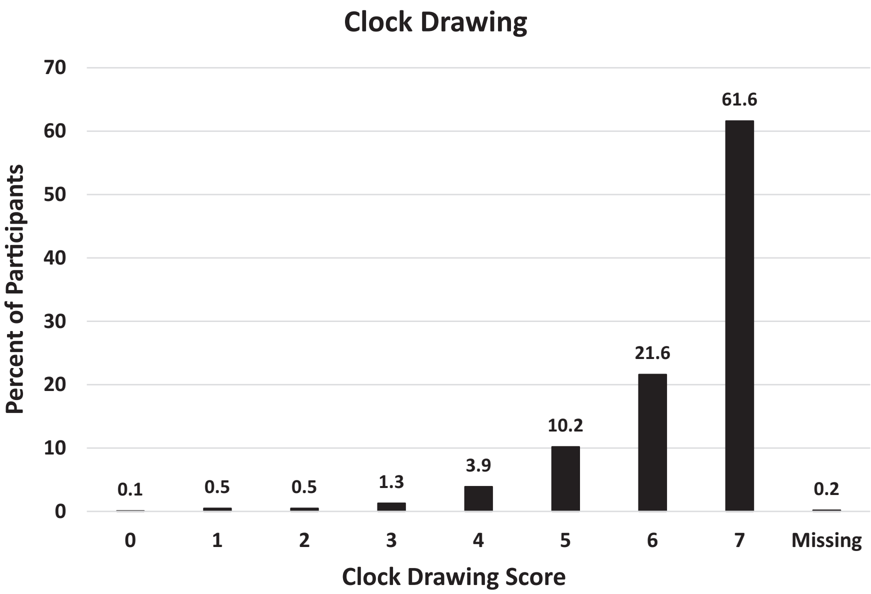

Fig. 4. Distribution of visuospatial ability scores as measured by the Clock Drawing test.

Table 2
The Overall Means, Standard Deviations (SD), Number of Participants (N), and Ranges for Cognitive Measures.

	N	Mean (SD)	Range
Retrieval Fluency (#)	2774	22.6 (6.3)	0–47
Trail Making A (*sec*)	2772	35.2 (12.8)	4.1–142.9
Trail Making B (*sec*)	2744	93.3 (45.5)	27.6–300.0
Simple Reaction Time (ms)	2622	349.0 (68.7)	20.0–858.8
Choice Reaction Time (ms)	2621	639.6 (122.8)	19.0–1273.5
Immediate Word Recall (score)*	2676	6.0 (1.6)	−2 to 10
Delayed Word Recall (score)*	2774	4.0 (2.0)	−7 to 10
Digit Symbol Substitution Test (score)*	2774	43.5 (10.1)	−25 to 82

* Score equals the number correct minus the number incorrect.

Table 3
RDE35 final multivariate model.

Predictor Measures	Estimate	SE	Wald Chi-Square	*p*-Value
# of trip chains	−0.575	0.0030	355.12	<0.0001
% of trips during AM peak	−0.0200	0.0040	24.68	<0.0001
% of trips during PM peak	0.0122	0.0044	7.63	0.01
% of trips less than 15 miles	0.0302	0.0009	1163.82	<0.0001
# of speeding events	0.0051	0.0011	22.48	<0.0001
Sex	0.1487	0.0392	14.41	0.0001
Site	0.0781	0.0133	34.65	<0.0001
Clock Drawing score	−0.0723	0.0181	15.90	<0.0001
Choice reaction time	0.0004	0.0002	6.09	0.01
Delayed Word Recall score	−0.0257	0.0094	7.47	0.01
Comfort in rush hour traffic	−0.0622	0.0177	12.32	0.0004
Comfort on freeways	0.0863	0.0212	16.61	<0.0001
Dispersion	0.6694	0.0228		

increase in the percent of trips during PM peak; the RDE35 rate increased 3 percent for every unit increase in the percent of trips less than 15 miles; and the RDE rate increased 0.3 percent for every unit increase in the # of speeding events.

Looking next at the demographic measures, age, income, and education were eliminated in the initial steps of multivariate modeling of the RDE35 rates for being non-significant. Sex and site were significantly associated with RDE35 rates

Table 4
RDE35 incident rate ratios for the final multivariate model.

Predictor Measures	Incident Rate Ratio ± 95% CI	*p*-Value
# of trip chains[a]	0.95 ± 0.01	<0.0001
% of trips during AM peak[a]	0.98 ± 0.01	<0.0001
% of trips during aPM peak[a]	1.01 ± 0.01	0.04
% of trips less than 15 miles[a]	1.03 ± 0.00	<0.0001
# of speeding events[a]	1.00 ± 0.00	0.002
Sex		
Female vs Male	1.13 ± 0.09	0.001
Site		
CO vs NY	1.69 ± 0.22	<0.0001
CO vs MD	1.25 ± 0.14	0.0001
CO vs MI	1.20 ± 0.15	0.001
CO vs CA	0.81 ± 0.09	0.0001
NY vs MD	0.74 ± 0.09	<0.0001
NY vs MI	0.71 ± 0.09	<0.0001
NY vs CA	0.48 ± 0.06	<0.0001
MD vs MI	0.97 ± 0.11	0.55
MD vs CA	0.65 ± 0.07	<0.0001
MI vs CA	0.67 ± 0.08	<0.0001
Clock Drawing[a]	0.92 ± 0.04	<0.0001
Choice reaction time[a]	1.00 ± 0.00	0.01
Delayed Word Recall[a]	0.97 ± 0.02	0.005
Comfort in rush hour traffic	0.94 ± 0.02	<0.0001
Comfort on freeways	1.07 ± 0.05	0.01

[a] Reference is per unit increase.

(Table 3). As shown in Table 4, the RDE35 rate for women was 1.13 times the rate for men; with the exception of the comparison between MI and MD, all other site comparisons had significantly different RDE35 rates, with CA having higher RDE35 rates than every site followed by CO.

The univariate models conducted for the perceptual and cognitive measures showed that six measures were significantly associated with RDE35 rates: Trail Making B, Clock Drawing score, choice reaction time, Immediate Word Recall, Delayed Word Recall, and DSST. These measures were included in the multivariate regression modeling for RDE35 rates. In the initial steps of multivariate regression modeling, Immediate Word Recall, Trail Making B, and DSST were eliminated for being non-significant. Clock Drawing score, choice reaction time, and Delayed Word Recall were significantly associated with RDE35 rates (Table 3). As shown in Table 4, the corresponding incident rate ratios showed that the RDE35 rate: decreased 8 percent for every unit increase (better performance) in the Clock Drawing score, increased 0.04 percent for every unit increase (worse performance) in choice reaction time, and decreased 3 percent for every unit increase (better performance) in Delayed Word Recall score.

With regard to self-reported driving comfort scenarios, night, unprotected left turns, bad weather, busy roads, unfamiliar areas, alone, at night in bad weather, and backing up were eliminated in the initial steps of multivariate regression modeling for being non-significant. Comfort in rush hour traffic and on freeways were significantly associated with RDE35 rates (Table 3). The incident rate ratios in Table 4 showed that the RDE35 rates decreased 6 percent for every unit increase in comfort driving in rush hour traffic and increased 7 percent for every unit increase in comfort driving on freeways. Separate multivariate modeling was conducted for the composite measure of driving comfort (with the composite measure replacing the scenarios) and this measure was not significant for either RDE35 or RDE75 rates.

The RDE75 rate zero-inflated Poisson multivariate regression modeling with backward selection showed that all predictor measures were non-significant except for percent of trips at night (estimate = 0.1019; SE = 0.0206; Wald Chi-Square = 24.54; $p < 0.0001$). The RDE75 incident rate ratio was 1.11 ± 0.04, indicating that the RDE75 rate increased 11 percent for every unit increase in the percent of trips at night.

5. Discussion and conclusions

This paper investigated factors related to RDE rates among a large cohort of older drivers using two empirically-based thresholds for an RDE—0.35 g and 0.75 g. Unlike Chevalier et al. (2017), the present study found very few RDEs when the threshold was defined as 0.75 g or greater deceleration. Chevalier et al. found that in the one year of driving among their 177 study participants, 64% had at least one RDE75, whereas we found that in one year of driving among our 2774 participants only 2% had at least one RDE75. This low incidence of RDE75s resulted in sample sizes that were too small for meaningful analyses of RDE75s in the present study and, therefore, hypothesis 2 could not be investigated. While we do not know the reason for this difference in the rates of RDE75, it is possible that the Chevalier et al. participants had lower functional abilities that were more likely to adversely affect driving behaviors. The Chevalier sample was considerably older than the

AAA LongROAD sample, with a median age (80 years) that was older than all AAA LongROAD participants at baseline. Furthermore, the older drivers in the Chevalier et al. sample drove considerably fewer miles than AAA LongROAD participants. The median annual number of miles driven for Chevalier et al. was 3452 as compared to 8416 for the AAA LongROAD participants. Low annual mileage of driving has been associated with greater crash involvement among older adults (see e.g., Hakamies-Blomqvist, Raitanen, & O'Neill, 2002; Langford, Methorst, & Hakamies-Blomqvist, 2006, Langford, Koppel, McCarthy, & Srinivasan, 2008).

The analyses of RDE35 rates found that two demographic covariates (sex and site), five objective driving measures (# trip chains, % trips AM peak, % trips PM peak, % trips 15 miles, and # speeding events), three functional ability measures (Clock Drawing, Delayed Word Recall, and choice reaction time), and self-reported level of driving comfort in two situations (driving in rush hour and on freeways) were significantly related to RDE35 rates. A summary of these findings is presented in Table 5, along with the prediction of the hypothesis relating the outcome measures to functional ability and driving comfort. In this table, one psychomotor and two cognitive covariates were significant in the direction predicted by our hypothesis; that is, RDE35 rates increased with decreases in functional ability as measured by these variables. In addition, we found that as reported levels of comfort decreased RDE35 rates increased, supporting hypothesis 1. Self-reported comfort with driving on freeways, however, was significant but in the opposite direction than predicted by the hypothesis.

These results contrast with the findings of Keay et al. (2013) and partially support the conclusion that RDE35 rates may have value as a surrogate measure of driving safety among older adults. However, the value of using RDE rates as a surrogate measure of driving safety is reduced by the other study findings. RDE35 rates also showed significant associations with outcome measures that were unrelated to driving abilities: demographics (sex); and the driving environment (site, driving during peak hours, speeding, and driving space). Indeed, the outcome measure that had the strongest relationship with RDE35 rates was the study site. Most likely this resulted from the variation in traffic density among sites. The sites with the highest RDE35 rates were San Diego, CA and Denver, CO—both with large, congested metropolitan areas. The site with the lowest RDE35 rate was Cooperstown, NY—a largely rural area. The traffic densities for trips were not available in the AAA LongROAD study. These results suggest that the use of 0.35 g deceleration as a threshold for a surrogate measure of driving safety is likely too low of a deceleration threshold. Coupled with the fact that nearly all participants in this study had at least one RDE35, it appears that this threshold is including, in addition to safety-relevant events, normal braking events that are not a driving concern.

Unlike both Chevalier et al. (2017) and Keay et al. (2013), we did not find any of the visual ability measures and few of the cognitive measures to be significantly related to RDE rates. One possible reason for this difference is that the AAA LongROAD participants at baseline were very healthy and high functioning compared to the older driver groups used in the other studies. In the Keay et al. (2013) study, for example, the sample's average contrast sensitivity (1.50) and Trail Making B time (130 sec) reflected poorer abilities than the AAA LongROAD participants' average scores (1.79 and 93 sec, respectively). It is expected that as AAA LongROAD participants continue in the study, they will start to experience declines in functional abilities as they age, and future analyses will be better able to address the relationship among RDE rates, functional abilities, and driving safety. Another possibility for the differences in results found between the present study and the Chevalier et al. (2017) and Keay et al. (2013) studies is that the previous studies used accelerometer data sampled at 32 hz and 10 hz, respectively, while the present study derived acceleration based on GPS data sampled at 1 hz. The lower sampling rate would be expected to miss some RDEs, especially some near the threshold.

In conclusion, RDE rates as defined as a longitudinal deceleration of 0.35 g or greater are related to declining functional abilities, but many other factors also play a significant role in the rate of RDE35s among older drivers, diminishing the value of using RDE35 rates as a surrogate measure of driving safety. In addition, because the AAA LongROAD sample was relatively healthy and high functioning, other ability-related covariates may also be significantly related to RDE35s but the lack of variance in these measures in the current study prevented these effects from emerging. Finally, RDEs defined as longitudinal decelerations of 0.75 g or greater may be a better surrogate measure of driving safety, but could not be investigated

Table 5
Summary of significant covariates with RDE35 rates across all analyses.

Category	Significant Covariate	Result	Support Hypothesis 1?
Demo-graphics	Sex	Women greater RDE35 rate	–
	Site	CA, CO greater RDE35 rates	–
Driving	# trip chains	RDE35 rate had 5% decrease for unit increase in #	–
	% trips AM peak	RDE35 rate had 2% decrease for unit increase in %	–
	% trips PM peak	RDE35 rate had 1% increase for unit increase in %	–
	% trips 15 miles	RDE35 rate had 3% increase for unit increase in %	Yes
	# speeding events	RDE35 rate had 0.3% for unit increase in #	–
Vision	Nothing significant	N/A	N/A
Cognition	Clock drawing	RDE35 rate had 8% decrease for unit increase in score	Yes
	Delayed word recall	RED35 rate had 3% decrease for unit increase in score	Yes
Motor	Choice RT	RDE35 rate had 0.04% increase for unit increase in ms	Yes
Comfort	Rush hour	RDE35 rate had 6% decrease for unit increase in score	Yes
	Freeways	RDE35 rate had 7% increase for unit increase in score	No

adequately in the current study because of a lack of these events. Further research should continue to compare the relationship of RDE rate thresholds, measures of abilities, and objective measures of traffic safety such as at-fault traffic crashes. The AAA LongROAD study includes collection of traffic crash data, but these data are not yet complete nor available for the participants included in this analysis. Future work on RDEs and driving safety will include both traffic crash and violation data in analyses.

Results of this study also suggest that the selection of a specific threshold for RDEs has important implications for which factors may be associated with this driving behavior, and what the safety outcomes might be. We selected two thresholds, RDE35 and RDE75, based on previous work in this area. Future research is needed that examines the full range of RDE thresholds to better understand the implications of rapid deceleration as a safety surrogate. For example as discussed in the introduction, there is evidence that an RDE threshold of 0.5 g or greater is related to near crashes among drivers of all ages (Dingus et al., 2006). Additional research should examine this RDE threshold among older drivers.

The strengths of this study included: the use of a large sample of older drivers who were recruited at five distinct geographic locations in the US; driving data over a full year after baseline; being able to exclude driving not performed by the AAA LongROAD participant; and the utilization of standard, objective measures of abilities. The AAA LongROAD cohort is relatively well-educated with high incomes and, therefore, not representative of all older adult drivers. As such, these results may not generalize to all older driver populations.

Declaration of Competing Interest

None.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2019.08.021.

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