Comparison of Older and Middle-Aged Drivers' Driving Performance in a Naturalistic Setting

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Declaration of interest: none

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Abstract

There is a concern about driving safety among older drivers due to the age-associated medical conditions. It is not known how these medical changes impact driving performance and choice of driving environment. This study aimed to compare older drivers' (≥74 years) driving performance in a naturalistic setting to middle-aged drivers (35-64 years) on their chosen driving environment, and number, type and severity of errors. The effect of sex and perceived driving ability was also examined. Drivers' performance was studied using the electronic Driving Observation Schedule [eDOS]), a naturalistic observation approach. Fifty-three older (mean age=80.6 years, 72% male) and 60 middle-aged (mean age=50.0 years, 50% male) healthy drivers were recruited. Both groups made few driving errors that were mostly low-risk. Driving performance of older adults differed from middle-aged drivers; they drove on simpler routes (fewer intersections and lane changes) and made fewer errors. Findings are likely indicative of older drivers' use of adaptive strategies to maintain safe driving.

Key words: aging, driving, naturalistic observation, route complexity, errors

1. Introduction

The number and proportion of older drivers in Canada and around the world is rapidly increasing. By 2036, it is estimated that one in every four Canadians will be aged ≥65 years (Statistics Canada, 2011). The private automobile remains the preferred and most popular means of transportation in older adulthood for accessing the community and participating in daily activities (Newbold et al., 2005; Sleightholm et al., 2010). The driving abilities of older adults is more likely to be impacted by health-related changes, compared to younger drivers. Various medical conditions known to affect visual, cognitive and psychomotor functioning (e.g. macular degeneration, dementia, Parkinson's disease) are more prevalent in older adults (Anstey et al., 2005). Such conditions, other comorbidities, as well as their associated medications can further impact driving ability (Canadian Medical Association, 2017). Older drivers tend to drive fewer kilometers per year compared to middle-aged drivers (Langford, Methorst, & Hakamies-Blomqvist, 2006) and report avoiding more complex driving situations (Naumann et al., 2011).

Older drivers often utilize adaptive decision-making strategies in the planning of the trip and maneuvering stages of driving, represented by the strategic and tactical levels of Michon's model of the driving task (Michon, 1985). These modifications, such as the selection of the driving route and time of day are often successful at maintaining safe driving in the older driver population. Modification of driving behaviors among older drivers may be due, in part, to declines in driving confidence, changes in lifestyle and habits, or because of self-imposed restrictions (Meng & Siren, 2012; Molnar et al., 2013; Molnar et al., 2014). Most studies examining older drivers' driving modifications rely on self-report, inquiring about avoidance of challenging road conditions, such as not driving at night, in unfamiliar areas, or in adverse weather (Blanchard & Myers, 2010; Molnar et al., 2014). In contrast, few studies have studied the complexity of the routes older drivers use to reach their everyday destinations and whether these actually differ from those used by younger drivers.

The complexity of a driving route is determined by the design of traffic lights and signs, the number of lanes, and speed limits in which the driver performs the maneuvers (e.g., left or right turn, lane change). Previous research has demonstrated that some types of driving environments and maneuvers are more challenging than others (Kay et al., 2008). Analyses of crashes using national or state-level data in the United States found that older drivers were over-represented in crashes occurring at intersections, especially where there were traffic signals and signs (Preusser, et al., 1998; Lombardi, Horrey, & Cortney, 2017). For example, drivers aged 70 years and older were more likely to be involved in at-fault crashes than non-at-fault crashes at intersections with a traffic signal (1.6 times for drivers aged 70-79 years; 3 times for drivers aged 80+ years) and at intersections with a stop sign (3 times for drivers aged 70-79 years; 7.5 times for drivers aged 80+ years). Conversely, drivers aged 30 to 60 years were under-represented in at-fault crashes at all types of intersections, with the ratio of at-fault crashes to non-at-fault crashes between 0.5 and 0.8 (Sifrit et al., 2010). Older drivers were also involved in more crashes than middle-aged drivers while making a left turn at an intersection (i.e., turning across traffic) (McGwin & Brown, 1999; Meyhew, Simpson, & Ferguson, 2006), driving in lower speed zones (< 30 mph) and on rural roads with fewer lanes (Lombardi, Horrey, & Cortney, 2017; McGwin & Brown, 1999). While it has been shown that crashes occur more often in certain driving environments and during specific maneuvers among older drivers compared to middle-aged drivers, the differences in the complexity of the driving routes chosen by these age groups during their everyday excursions are not well understood.

Many drivers with considerable years of experience perform some inappropriate driving maneuvers, which may be either bad habits that are relatively harmless, or they may pose a risk (Baldock et al., 2006; Kay et al., 2008). Analysis of crash data reveals some important differences in the types of critical errors made by older and middle-aged drivers. For example, older drivers exhibited inadequate surveillance, including a lack of environmental observation, looking but not seeing other vehicles, road users or traffic controls, misjudging other vehicles' speed and distance, and failing to yield the right of way (Braitman et al., 2007; Classen et al, 2010; Cicchino & McCartt, 2015; McGwin & Brown, 1999; Preusser, et al., 1998). The middle-aged drivers were more likely to speed, made more errors in the use of vehicle controls (e.g. overcompensation in urgent situations), and were involved with more distractors (Braitman et al., 2007; Cicchino & McCartt, 2015). While there is some understanding of the consequences of major driving errors, there is little information on the specific circumstances under which different types of errors occur.

Research using standard on-road driving evaluations as well as those conducted in simulators have provided useful information on how healthy older and middle-aged adults drive differently in real or virtual traffic situations. One Australian study (Koppel et al., 2015) reported that both older and middle-aged drivers had a high proportion of appropriate driving behaviors (middle-aged drivers: M= 87.6%, SD= 9.04; older drivers: M= 87.0%, SD = 6.96), and that there was no significant difference in overall driving performance between the two groups on a standard on-road driving evaluation ($t(8) = 0.12$, $p = 0.91$). The authors found that older drivers tended to engage in more inappropriate driving behaviors when turning in a direction that crosses traffic (i.e. left turns in North America and Europe; right turns in Australia) at uncontrolled intersections, as well as when navigating roundabouts. However, this pilot study included only five participants per group and, as such, the results were considered preliminary. Another study conducted in the United States found that older drivers had a significantly lower overall safety rating compared to middle-aged drivers. Driving errors were recorded by trained occupational therapists and indicated that older drivers made more errors than middle-aged drivers, especially in lane positioning (Wood & Mallon, 2001). A driving simulation study obtained similar results; more older drivers had crashes during the drive compared to middle-aged drivers (Park et al., 2011). In addition, older drivers were more likely to have difficulty following the indicated speed, veered out of their lane more often, and made more errors when lane changing. These difficulties were linked to problems with cognitive-perceptual ability (e.g. sustained and divided attention) (Park et al., 2011). While the literature suggests that there are differences in driving performance between middle-aged and older drivers, there have not been any studies to date examining the driving errors that occur under naturalistic conditions, which are more reflective of everyday driving.

The naturalistic approach to observing driving is an unobtrusive way to study driving behavior in everyday environments. This approach aims to minimize the effects of researchers' or clinicians' presence and the interference of an evaluator, thereby decreasing the stress associated with the on-road standard driving evaluation. Naturalistic driving is more representative of day-to-day driving, and avoids the structured setting typically used for clinical or research purposes (Chen, Gélinas, & Mazer, 2018). Using this approach may increase our knowledge of the complexity of everyday driving environments and the driving errors that occur in healthy aging and explain how these errors might differ from younger, low-risk drivers.

Research suggests that older adults' choice of driving environment and their corresponding driving performance may be related to sex and perceived driving ability, but evidence from such research is not yet conclusive. Community dwelling older female drivers were found to have less confidence in driving (D'Ambrosio et al., 2008), avoided more challenging driving conditions (Molnar et al., 2014), and were less likely to fail a standard on-road driving evaluation than their male counterparts (Classen et al., 2013). These findings suggest that female drivers may adopt a more conservative driving style than males, but the relationship has not yet been examined under naturalistic driving conditions. In addition, crash scene investigations show that male and female older drivers make different types of critical errors. While inadequate surveillance of road conditions is the most frequent error type made by both sexes, older female drivers made more errors in gap or speed judgement, while older male drivers made more illegal maneuvers (e.g., failure to obey traffic signs) (Cicchino & McCartt, 2015). There is a need to clarify the association of sex and perceived driving ability among older and middle-aged drivers in naturalistic driving conditions.

While past studies have used self-report and standard on-road driving approaches to demonstrate the different types of driving errors and driving environment modification strategies between middle-aged and older drivers, the manner in which these two cohorts drive in their natural driving environment is not well understood. In addition, by using the naturalistic driving study approach, it is possible to examine the extent to which drivers choose to drive on routes or environments that have lower risks. The primary objective of this study was to compare the driving performance in a naturalistic setting of healthy older adults ($\geq$74 years) to middle-aged low-risk adults (35-64 years) in terms of their chosen driving environment (i.e., complexity of maneuvers and routes), as well as the number, type and severity of driving errors. The secondary objective was to examine the effect of sex and perceived driving ability on driving performance in a naturalistic setting of older and middle-aged drivers.

2. Methods

2.1 Participants

All participants were active, healthy drivers recruited from an urban community through advertising and snowballing. Older drivers were recruited from the Montreal site of the Candrive national longitudinal cohort study (see Marshall et al., 2013). The Candrive study, a prospective multicenter study involving seven Canadian sites (Ozcandrive was a parallel study with two sites in Australia and New Zealand), recruited 928 older drivers, at least age 70 years (62% male). They underwent an annual comprehensive in-person evaluation that included medical history, driving history, physical examination, cognition screening, and questionnaires related to driving attitudes and perceptions. The primary outcome measure was a police-reported, expert-validated, at-fault collision-adjusted per annual distance driven. Eligible participants for the current analysis were: aged ≥74 years, drove at least once a week, spoke English, and were under the care of a family physician. Participants were excluded from the study if they had a severe contraindication to driving, such as a stroke or severe vision problems. All participants who were eligible to participate for the current study were approached.

Middle-aged drivers were eligible if they were aged 35-64 years, the age range associated with the lowest crash risk. All other eligibility criteria were the same as for the older driver group. These participants were recruited through convenience sampling from the community in Montreal. The target sample size of the middle-aged drivers was 60 adults and, to ensure representation of age and sex, the recruitment was stratified: 10 males and 10 females within each of the age ranges of 35-44, 45-54, and 55-65 years.

2.2 Measures

2.2.1 Electronic Driving Observation Schedule (eDOS)

The eDOS is an observational tool developed by the Candrive/Ozcandrive research team to record and monitor older adults' everyday driving environment and behaviors, as well as potential changes over time (Koppel et al., 2013, 2016, 2017; Vlahodimitrakou et al., 2013). Two research assistants (RAs) begin the eDOS observation at the home of the participant where they are asked to drive in their own vehicle to one or two destinations that they select (e.g., shopping mall, medical office, church) and then back home again for a total drive of approximately 25 minutes. This entire route, whether to one or two destinations, is analyzed as one drive. Participants are encouraged to select their usual routes to these destinations and to drive as they normally do during their daily routine. In the original version of the eDOS developed in Australia, the RA sat in the participant's vehicle to conduct the observations. This method was modified in the current study so that the RAs observe the drive from a following car. One RA drives a vehicle that follows the participant's vehicle, while the second RA records the participant's driving environment and behaviors using the eDOS scoring sheet on a tablet (see Figure 1).

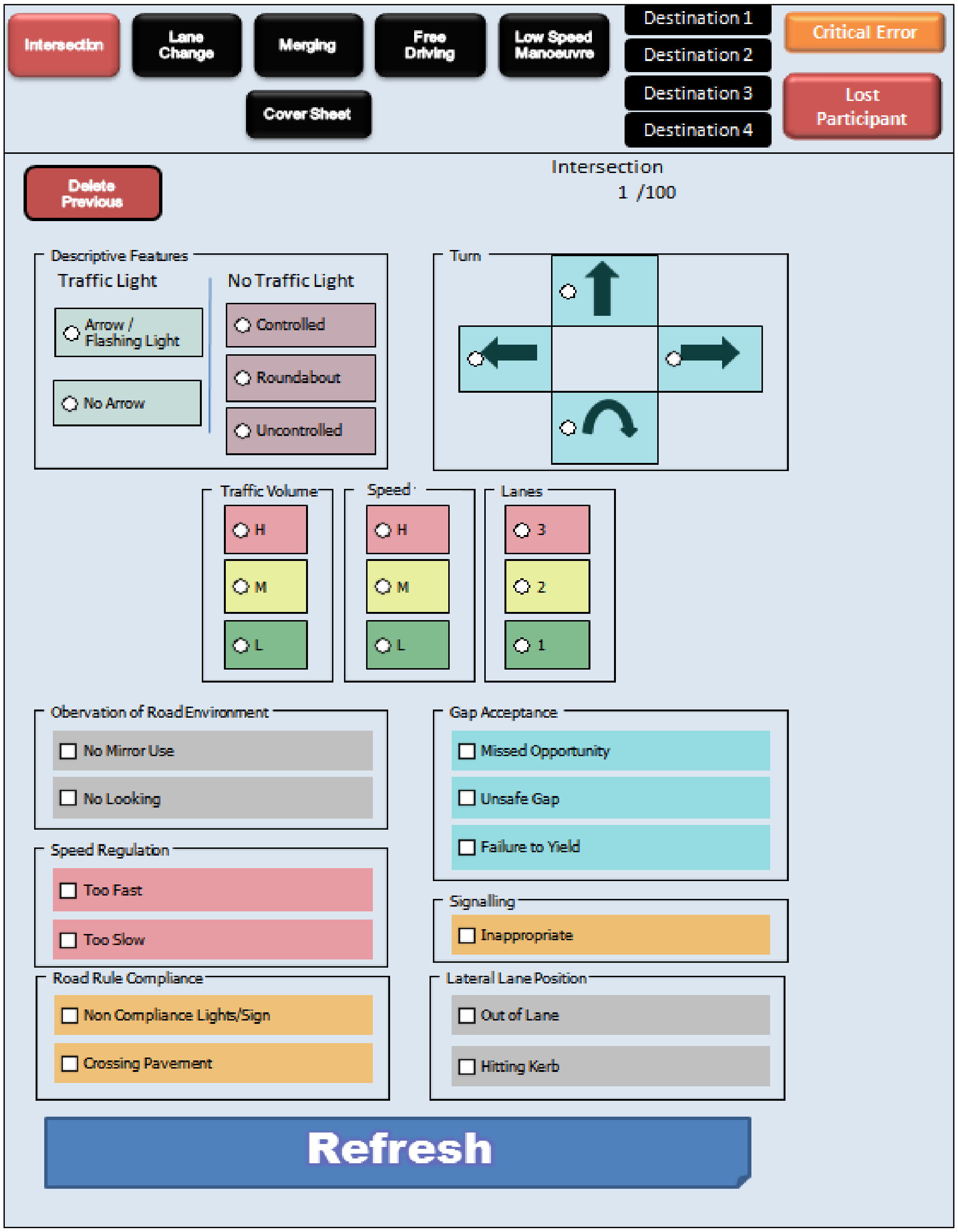

Figure 1. An example of the eDOS electronic scoring sheet (for intersections) (Koppel et al., 2013)

The complexity of driving routes is determined by the number and type of maneuvers made at different levels of environmental complexities. For each maneuver, including passing through or turning at an intersection, changing lanes, or merging into traffic, the driving environment (i.e., traffic signs and signals, traffic volume, speed zone, and number of lanes) is recorded from 1 (low complexity) to 3 (high complexity). The average of all driving maneuvers and their environmental context is used to generate the weighted driving maneuver/environment complexity score, ranging from 1-3 (Chen, Gélinas, Mazer, 2020).

Similarly, at each maneuver, drivers' behaviors are recorded as 'appropriate' or 'inappropriate'. Inappropriate driving behaviors, or driving errors, are recorded on the bottom half of the eDOS scoring sheet, and are categorized into five or six different types, including: environment observation (e.g., scanning), speed regulation, road rule compliance (e.g., rolling stop), gap acceptance, signaling (e.g. not signaling at a turn or lane change [most common], signaling when not appropriate, keeping signal on very long after a lane change or turn), and lane position (e.g., wide turns), depending on the type of maneuver (for detailed definitions, see Vlahodimitrakou et al., 2013). In this study, since the RAs did not observe drivers in their car, the error type of 'environment observation' could not be accurately scored and was excluded from the analysis. For each driving error made, a weight is given (1=low risk error; 2=moderate risk error; 3=high risk error), based on the type of error and the environment where the error was made. For example, no signaling at an intersection with only one lane in a low-speed zone is classified as a 'low risk' error, whereas choosing an inappropriate gap to make a left turn on a boulevard is rated as a 'high risk' error. The weighted eDOS total score is calculated as the sum of errors weighted for its risk level. Higher weighted eDOS total scores indicate a higher number and/or greater risk of driving errors made throughout the drive. The driving maneuver/environment complexity score and the weighted eDOS score were developed by a review of literature and a two-round on-line survey conducted with experts in driving rehabilitation (Chen, et al., 2020).

A short survey is conducted at the end of the drive to examine drivers' level of comfort with being observed during the eDOS drive. They are asked to give a rating from 1=completely uncomfortable to 5=completely comfortable.

One study examined the psychometric properties of the original, non-electronic version of the eDOS, and reported good inter-rater reliability (ICC=0.91; 95% CI=0.75-0.97; $p<0.0001$) and internal consistency ($r(18)=0.83$; $p<0.05$). The eDOS was found to have good ecological validity with regard to reflecting drivers' everyday driving routes and corresponding behavior, as well as a high level of comfort and acceptability with the approach from the participants' perspective (Vlahodimitrakou et al., 2013).

2.2.2. Perceived Driving Abilities (PDA) Questionnaire

The PDA is a questionnaire designed to assess self-perception of current driving ability and perceived changes in driving ability compared to 10 years prior. The PDA includes 15 items (e.g., general ability to drive safely, ability to see road signs, ability to make quick decisions) in each section. Every item is scored from 0 (poor) to 3 (very good), with a maximum total score of 45. Higher scores represent a better self-rating of driving ability. The total score was found to be unidimensional & hierarchical, with excellent person ($r=0.92$) & item ($r=0.96$) reliability (MacDonald, Myers, & Blanchard, 2008). This study focused only on the participants' perception of current driving ability and did not include the changes in driving ability over time.

2.3 Procedures

This study obtained approval from the Research Ethics Board of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR-4110209). Eligible participants were contacted by one of the RAs and, once verbal consent was obtained, an appointment for the driving observation was made. On the day of the observation, participants were asked to sign the informed consent form, complete the PDA questionnaire, and drive in their own vehicle from their home to their selected destination(s) following the eDOS procedure. For older drivers, the PDA questionnaire was completed during the Candrive annual assessment. To lower the test burden, their PDA scores were extracted from the annual assessment if the questionnaire was completed within 90 days of the driving observation. The observation was rescheduled if the driver indicated that he or she usually avoided driving in certain conditions, such as severely congested traffic or poor weather conditions.

2.4 Data Analysis

Descriptive statistics were used to present the demographic information, eDOS total scores, eDOS comfort level, duration and distance driven, and the PDA scores. The average number of each driving maneuver was reported. Since the total number of maneuvers varied during each drive, the percentages of specific types of inappropriate maneuvers were calculated and used for further group comparisons.

To compare the outcome variables between older and middle-aged drivers, continuous variables were compared using independent t-tests. Effect size indices for inferential analyses were calculated. Absolute Cohen's d values were reported for independent t-tests. Cohen's $d < 0.20$ is considered as a small effect size, reaching 0.5 as a medium effect size, and 0.8 as a large effect size (Cohen, 1988). Partial eta squares (η^2) were reported for ANOVA; $\eta^2 < 0.01$ indicates a small effect size, $\eta^2 = 0.06$ indicates a medium effect, and $\eta^2 = 0.14$ indicates a large effect size" (Cohen, 1988). Categorical, ordinal variables, or continuous variables that were not normally distributed were compared by corresponding non-parametric statistical methods, such as the Chi-square test and Wilcoxon rank sum test.

To examine the independent effect of sex on driving performance and environmental complexity, older and middle-aged drivers' eDOS data were combined and analyzed using independent t-tests. The effect and interaction of sex and age group on driving performance was examined using a two-way ANOVA. Tests of the assumptions for the two-way ANOVA indicated that not all assumptions were satisfied for the outcome variable (Shapiro-Wilk test for the normality of data distribution=0.86-0.94, $p<0.005$; Levene's test for the homogeneity of variances: $F=3.52$, $p=0.017$), potentially leading to an increased risk of committing a type I error (Portney & Watkins, 2009). One participant in the older group was considered an outlier as the person's weighted eDOS total score was >3 SD worse from the mean, and this participant was therefore removed from this analysis. The assumptions of normality and homogeneity were then satisfied, allowing for the use of the two-way ANOVA. The relationship between PDA scores and driving performance was also examined using Pearson correlation.

3. Results

Fifty-three older and sixty middle-aged drivers completed the study. The mean (SD) age of the older and middle-aged groups was 80.6 (5.0) years and 50.0 (8.6) years, respectively. The sample of older drivers consisted of a significantly higher proportion of males (72%) while the middle-aged group were evenly distributed (50% male) ($\chi2(1)=5.53$; $p=0.02$).

Participants in both the older and middle-aged groups drove approximately 10 kilometres and took 25 minutes to complete the eDOS drive. No significant differences were found across the two age groups in terms of the overall complexity of the driving routes, however, older drivers had a lower average weighted eDOS score (weighted for severity of driving errors and complexity of driving environment) compared to middle-aged drivers, indicating better performance during the drive (Table 1).

There were 29 older and 59 middle-aged drivers who had valid PDA scores; there were no significant differences in the results between the two groups (Table 1). The following results present the specific details of the differences and similarities in driving environments and errors between the two groups.

Table 1. Comparison of the eDOS driving trip characteristics, total eDOS scores and PDA scores between older and middle-aged drivers

	Score range (min-max)	Older drivers (n=53)			Middle-aged drivers (n=60)			t	*p*	*Effect size (d)*
		M	*SD*	*Range*	*M*	*SD*	*Range*			
Weighted eDOS total score[§]	0-∞	7.0	8.8	0 - 51	16.3	9.5	0 - 37	5.4	<0.001*	1.01
Weighted maneuver/ environment score	1-3	1.6	0.2	1.2 - 2.0	1.6	0.1	1.3 - 1.9	0.4	0.68	0.00
Duration (min, s)	na	25’58”	7’19”	13’12” – 49’40”	25’37”	5’11”	16’20” - 41’03”	0.3	0.77	0.06
Distance driven (km)	na	10.4	3.7	3.4 - 15.2	9.6	2.1	5 - 16	1.4	0.17	0.27
eDOS comfort rating	1-5	4.6	0.8	2 - 5	4.8	0.6	2 - 5	-0.9	0.33	0.29
PDA current score	0-45	37.7	5.1	27 - 45	38.4	6.5	20 - 45	0.6	0.59	0.12

Note. eDOS=electronic Driving Observation Schedule; M = mean; PDA=Perceived Driving Abilities Questionnaire; SD = standard deviation.

*p<0.05

§ Lower scores represent better performance

3.1 Complexity of Driving Routes

Because the average distance and duration of the eDOS drive were similar between the two groups, the types of routes could be compared. Older drivers chose routes with significantly fewer intersections than middle-aged drivers and made fewer lane changes (See Table 2). Six (11.3%) of the older drivers did not make any lane change maneuvers, while all participants in the middle-aged cohort had at least one lane change maneuver (Fisher's exact test=0.009, $p<0.05$). The total number of merges and the proportion of drivers who did not merge during the drive did not differ between the two groups. In both groups, approximately half of the drivers did not make any merging maneuvers (older drivers: n=31; middle-aged drivers: n =33).

Table 2. Comparison of the average number of maneuvers per eDOS drive between older and middle-aged drivers

	Older drivers (n=53)		Middle-aged drivers (n=60)		t	*p*	*Effect size (d)*
	M	*SD*	*M*	*SD*			
Number of intersections	38.9	9.9	47.5	9.8	4.7	<0.001*	0.87
Left turn	8.3	2.5	10.6	3.6	3.9	<0.001*	0.73
Right turn	9.7	3.3	11.5	2.9	3.0	<0.001*	0.58
Straight through	15.9	7.5	19.7	8.3	2.5	0.02*	0.48
Others (roundabout, U-turn)	4.9	4.4	5.9	5.7	0.7	0.51	0.19
Number of lane changes	4.7	3.8	6.4	3.5	-2.5	0.01*	0.47
Left to right	2.2	2.0	3.1	2.1	2.4	0.02*	0.44
Right to left	2.3	2.2	3.4	2.3	2.0	0.05	0.49
Number of merges	0.9	1.4	0.6	0.7	1.7	0.09	0.18

M = mean; SD = standard deviation; *$p<0.05$

The complexity of driving route also depends on the traffic volume, speed zone, and the number of lanes where a driver conducts each maneuver. Table 3 presents the findings for these variables at each intersection for the older and middle-aged groups. Though very few, older drivers had a higher proportion of maneuvers at intersections with a high traffic volume (t=2.01, *p*=0.049) and with only one lane (t=4.64, *p*<0.001). Middle-aged drivers had a higher proportion of maneuvers at intersections with three or more lanes (t=-4.47, *p*<0.001). There were no differences in the speed zones between the two groups.

Table 3. Comparison of the mean percentage of driving environment characteristics at intersections between older and middle-aged drivers

	Older drivers (n=53)		Middle-aged drivers (n=60)		t	*p*	*Effect size (d)*
	M	*SD*	*M*	*SD*			
Traffic volume							
Low	54.5	19.8	61.6	18.3	-1.96	0.05	0.37
Median	43.5	18.7	38.1	18.0	1.56	0.12	0.29
High	1.4	4.3	0.1	1.1	2.01	0.049*	0.43
Speed zone							
Low (≤ 40 km/h)	57.8	17.6	58.6	18.6	-0.24	0.81	0.04
Median (41-79 km/h)	41.4	17.6	41.1	18.6	0.09	0.93	0.02
High (≥ 80 km/h)	0.0	0.0	0.0	0.0	1.00	0.32	NA
Number of lanes							
1	74.8	17.5	59.0	18.6	4.64	<0.001*	0.87
2	15.3	11.7	19.7	14.0	-1.82	0.07	0.34
≥3	9.8	11.7	20.8	16.6	-4.47	<0.001*	0.76

M = mean; SD = standard deviation; *p<0.05

3.2 Number, Type, and Severity of Driving Errors

Most drivers in both groups made at least one error at an intersection; 17% of the older drivers and 2.3% of the middle-aged drivers did not make any errors at intersections (Fisher's exact test=0.006, $p<0.05$). Table 4 presents the average proportion of intersections with each error type during the eDOS drive for both groups. Middle-aged drivers made significantly more errors than older drivers, specifically errors related to signalling (primarily not signaling), lane positioning and road rule compliance.

Table 4. Comparison of average proportion of intersections with each error type between older and middle-aged drivers

	Older drivers (n=53)		Middle-aged drivers (n=60)		t	*p*	*Effect size (d)*
	M	*SD*	*M*	*SD*			
Errors at intersections							
% with errors	6.8	7.8	15.4	8.8	-5.5	<0.001*	1.03
Signaling	4.6	5.8	8.0	6.1	3.0	0.004*	0.57
Speed control	0.3	1.0	0.8	1.9	2.0	0.05	0.32
Gap selection	0.2	0.6	0.1	0.5	0.3	0.80	0.18
Lane position	0.5	1.5	3.0	2.3	6.6	<0.001*	1.27
Road rule compliance	1.5	3.6	4.4	5.7	3.3	0.002*	0.60

M = mean; SD = standard deviation; *p<.05

Due to low number of driving errors recorded during lane changes and merging, the types of driving errors made in these two maneuvers were reported descriptively. During lane changes, the average number of errors did not differ between the two groups. Approximately 45% of drivers in both groups made at least one error during a lane change (χ^2=0.001, *p*=0.97). Eighty percent of the lane changes conducted by the older drivers were 'appropriate,' compared to 84% in the middle-aged group (Wilcoxon rank sum test Z=-0.23, *p*=0.82). The majority of errors made in both groups during lane changes were signalling errors (40 out of 47 errors in the older group and 56 out of 63 errors in the middle-aged group). In contrast, middle-aged drivers made more errors while merging compared to older drivers (Wilcoxon rank sum test Z=-2.46, *p*=0.01). Only one error was recorded in the older driver group, while nine errors were made by the middle-aged group (by nine different drivers). All the errors recorded during merging were signalling errors (i.e. not signalling).

The comparison of the risk level of driving errors made in different maneuvers between older and middle-aged drivers are presented in Table 5. Middle-aged drivers had a significantly higher percentage of moderate-risk total errors during the drive compared to older drivers.

Table 5. Comparison of the percentage of errors at each risk level for each type of maneuver between older and middle-aged drivers

	Older drivers (n=53)		Middle-aged drivers (n=60)		t	*p*	*Effect size (d)*
	M	*SD*	*M*	*SD*			
Total errors							
Low-risk	40.8	47.2	35.4	18.9	0.9	0.36	0.15
Moderate-risk	31.0	33.5	42.6	21.4	-2.1	0.04*	0.42
High-risk	28.2	31.5	22.0	20.4	1.2	0.25	0.24
Intersection errors							
Low-risk	51.4	38.8	40.7	20.9	1.7	0.10	0.35
Moderate-risk	32.8	35.8	43.5	24.0	-1.7	0.09	0.36
High-risk	15.7	29.9	15.7	19.2	0.0	1.0	0.00

Lane change and merging errors							
Low-risk	0	0	0	0	--	--	NA
Moderate-risk	25.3	38.2	32.0	43.6	-0.6	0.54	0.16
High-risk	74.7	38.2	68.0	43.6	0.61	0.54	0.16

M = mean; SD = standard deviation; *p<.05

3.3 The relationship of sex, PDA scores, and driving performance

While female drivers tended to have lower PDA scores, drove on simpler routes, and had better driving performance than male drivers, these differences were not statistically significant (perceived driving ability: t=1.16(86), p=0.25, d=0.25; weighted maneuver/environmental complexity score: t(111)=0.71), p=0.48, d=0.13; weighted eDOS total score: t(111)=0.26, p=0.80, d=0.05). However, female drivers reported a higher comfort level during the eDOS drive (i.e., the eDOS comfort score) compared to male drivers (male mean (SD)= 4.21(1.60); female mean(SD)=4.73(0.65); t=-2.43(95.38); p=0.02, d=0.40). PDA scores were also not significantly related to weighted eDOS total score (r=.09, p=.39) or the complexity of driving environment (r=-.05, p=.62).

There were no statistically significant differences in the types of maneuver and percentage of challenging maneuvers (e.g., left/right turns or left turns at uncontrolled intersections) between male and female drivers. Also, there were no sex differences in the percentage of driving errors at intersections, lane changes, and merging, except that male drivers made more gap selection errors at intersections than female drivers (t=2.53(67); p=0.01, d=0.39). Six male drivers (three older drivers and three middle-aged drivers) made gap selection errors, while none of the female drivers made these types of errors.

The two-way ANOVA indicated that there was a main effect of age on driving performance ($F=41.93$, $p<0.001$, $\eta 2 = 0.22$), but not sex($F=1.86$, $p=0.18$, $\eta 2 = 0.02$). There was no interaction between age and sex on the weighted eDOS total score ($F=0.002$, $p=0.96$, $\eta 2 = 0.01$). Older drivers had lower eDOS scores compared to middle-aged drivers, and this relationship was not influenced by sex. These eDOS scores reflect the combined effects of older drivers choosing simpler and less complex routes and making fewer errors when driving on them.

4. Discussion

This study compared the complexity of the driving environment and the driving errors made by older and middle-aged drivers under naturalistic driving conditions. The effect of sex and participants' perceptions of their current driving ability on driving performance was also examined. Overall, older drivers exhibited lower eDOS scores compared to middle-aged drivers. This finding reflects the combined effect of older drivers choosing less complex routes and making fewer errors when driving on these routes. Older drivers chose routes with fewer intersections and performed fewer lane changes; in fact, a proportion of older drivers did not have any lane change maneuvers recorded. These findings may be indicative of older adults' self-regulatory behaviors adopted to maintain driving performance and safety, either consciously or unconsciously, by travelling on quieter one-lane roads where lane changes were not possible or taking routes to reach destinations without the necessity of lane changing. Nevertheless, we did not find that older drivers avoided more challenging maneuvers in complex environments, such as turning left at uncontrolled intersections. This result was also found in a previous study that examined the reasoning for older drivers' selection of daily driving routes. The authors concluded that older drivers tend to choose routes with high familiarity, disregarding the suggested, alternative lower risk routes (e.g., fewer number of left turns and U-turns) (Payyanadan, Sanchez, & Lee, 2019).

Compared to middle-aged drivers, fewer older drivers made errors at intersections and merging. Since most of the maneuver recordings were at intersections, older drivers' lower error rates during these types of maneuvers could largely explain why they had better overall driving performance scores. While past studies showed that older drivers are over-represented in crashes occurring at intersections, especially while making left turns (Lombardi, Horrey, & Cortney, 2017; McGwin & Brown, 1999; Meyhew, Simpson, & Ferguson, 2006), and that healthy older drivers commit more errors in standard on-road driving evaluations than middle-aged drivers (Wood & Mallon, 2001), the results from our observation of driving performance in a naturalistic setting were inconsistent with these findings. This may be explained by differences in the types of samples between studies and the use of the naturalistic context used in this study. Older drivers in this study were recruited from the Candrive longitudinal cohort study using convenience sampling. Compared to the general older driver population, these older drivers were likely to be more active and healthier and may have more accurate self-awareness of their driving ability due to their long-term participation in driving-related research. Moreover, observing older drivers' performance in their natural driving environment may provide a more comfortable and less stressful situation compared to the standard on-road driving evaluation, which is conducted in an unfamiliar test vehicle and novel driving environment (Chen, Gélinas, & Mazer, 2018). The stress related to this type of evaluation is more likely to negatively affect older adults' driving performance than that of younger drivers (Fairclough, Tattersall, & Houston, 2006). In addition, one study examined driving behavior using the driving simulator in a car-following task showed that older drivers (60+ years) adopted more compensatory processes, such as keeping longer headways, and anticipated traffic events more frequently, compared to younger participants (26-40 years) (Andrews and Westerman, 2012). While our study showed older adults made fewer driving errors in naturalistic driving settings than younger adults, how drivers perform differently in different driving contexts and the impacts of age will need further investigation.

A high percentage of errors made by drivers in both age ranges were non-critical and may be considered poor driving habits (Classen et al, 2010; Dobbs et al., 1998). Ninety-five percent of the errors made in the older group and 85 percent of the errors in the middle-aged group were inappropriate signaling, speed regulation, and rolling stop. This finding is similar to past research results. One Canadian observational study reported that the overall rate of using turn signals is only 76 percent, ranging from 54 percent to 95 percent (Faw, 2013). Another study found no differences in the proportion of drivers who signal appropriately between various age groups from 20 to 70 years, however, it is not known whether the rate is maintained in older age groups (Sullivan, Bao, Goudy, & Konet, 2014). Dobbs and colleagues (1998) studied older drivers and suggested that rolling stops and failure to adjust speed errors should not be considered indicative of decline in driving competence, as they are typical errors made by drivers with years of driving experience.

Other than these habitual, non-critical errors, our study also found that older drivers and middle-aged drivers did not perform differently in the proportion of high-risk errors made during the drive. These types of errors were suggested to discriminate at-risk older drivers from competent drivers (Classen et al, 2010; Dobbs, Heller, & Schophlocher, 1998; Wood & Mallon, 2001). These errors, as defined in the literature, include inappropriate lateral positioning, overcautiousness (e.g., driving too slow), inappropriate turning position (e.g., wide turns), observation and scanning errors, and sudden brake and acceleration (Classen et al, 2010; Dobbs, Heller, & Schophlocher, 1998; Wood & Mallon, 2001). It is quite possible that this sample of healthy older drivers were not at high risk.

In contrast to past studies that found middle-aged drivers made fewer signalling errors (Wood & Mallon, 2001), scanning errors (Dobbs et al., 1998), and lane positioning errors (Wood & Mallon, 2001) than healthy older drivers in a standard on-road driving evaluation, our results showed that middle-aged drivers had a higher rate of signalling, lateral lane position, and compliance to road rules errors in the context of a naturalistic driving observation. It is conceivable that younger drivers are more distracted by secondary tasks in everyday driving contexts (Huisingh, Griffin, & McGwin Jr., 2015; Sullman, Prat, & Tasci, 2015), leading them to be less careful and less likely to follow the traffic rules and signs. However, our research methodology did not enable in-car observation of drivers' behavior. It is also possible that, rather than an age effect, there is a cohort effect, meaning that driving behaviors and habits may vary over different generations. As middle-aged drivers and older drivers had different driving-related training, experiences, and traffic conditions when they learned to drive and throughout their driving life, the two cohorts may have developed different driving habits.

Contrary to previous research (D'Ambrosio et al., 2008; Molnar et al., 2014), the results of this study did not find a significant relationship between either sex or perceived driving ability with driving environment complexity and overall performance, except male drivers made more gap selection errors than female drivers. While analysis of crash data has shown that older female drivers make more gap or speed misjudgements than older male drivers (Ciccino & McCartt, 2015), more in-depth studies with larger sample size will be needed to investigate age and sex differences in greater detail.

There are several limitations to this study that should be considered. First, the participants were a healthy group of older drivers, with few medical conditions, and the results may not be generalizable to the general older driver population. Second, because observers were not seated in the participants' cars, drivers' in-car behaviors could not be recorded, therefore, mirror use, environmental observation or scanning errors were not observed. Having this information could further explain any differences in driving behaviors between the older and middle-aged cohorts. Finally, since the study was undertaken in one Canadian city and the surrounding area, findings from this study may not be representative of drivers in other locations.

In order to gain more insight into the driving style and errors made by drivers of different generations, future research could examine different cohorts longitudinally. A larger sample size from different locations may be needed to examine the relationship of other potentially confounding factors, such as health, demographic, and economic factors. Also, a deeper analysis of the types and reasons for the observed errors, whether bad habits, omissions, or willful violation of the law, would add further context to the differences between the age groups. A future more complex analysis using a larger sample is proposed to better understand the interaction between environmental complexity and errors. Using data from in-car recording devices, such as video clips and car engine data, would also enhance the detailed analysis of driving behaviors and errors in different age groups.

5. Conclusions

Overall, middle-aged and older drivers in this study made few driving errors and these were generally low-risk errors. When comparing the naturalistic environment that drivers of varying ages tended to use, older drivers executed fewer turns at intersections, possibly self-regulating their routes to minimize risk. The finding that older drivers had lower eDOS scores compared to middle-aged drivers is likely indicative of the combined effect of choosing less complex routes, which possibly presented fewer opportunities for errors, along with making fewer errors while driving along these routes. Findings are likely indicative of older drivers' use of adaptive strategies to maintain safe driving.

Acknowledgements

The authors would like to thank the Candrive Program Manager, Lynn MacLeay, for managing the Candrive II study, and the Candrive Research Associates, Rivi Levkovich and Catherine Demers, for participant recruitment and data collection. The authors also thank the study participants for their dedication and participation.

Funding: This work was supported by the Canadian Institutes of Health Research (CIHR) [grant number 90429]; the Auto21 Network of Centres of Excellence [grant number A503-AOP]; the Australian Research Council Linkage Grant (grant number LP100100078).

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