Speed and acceleration patterns of younger and older drivers

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Abstract

Driving and aging is an area that is receiving more research attention. Most studies have been epidemiological or laboratory-based. Few studies have examined in-vehicle performance, and those that do usually rely on the subjective evaluation of an observer inside or outside the vehicle. The purpose of this study was to examine driver-induced vehicle longitudinal movements under real life conditions in younger (30 - 50 years) and older (≥70 years) men and women. It was hypothesized that both the younger drivers and the male drivers would show higher speed and acceleration related values. A total of 49 drivers (13 younger men, age 37.8 ± 5.9; 12 younger women, age 40.2± 7.1; 13 older men, age 76.0 ± 4.6; and 11 older women, age 76.7 ± 5.5) drove a 26 km road course which included residential, collector, arterial and highway roads with 30 intersections. The vehicle movement data were collected by a Global Positioning System (GPS) receiver which was installed in each subject's own vehicle. In addition, the scene in front of the driver was captured using a digital video camera, without the image of the driver, to provide context for the GPS data. The following maximum speed data were analysed: 1) the whole road course, 2) within all the sections between the 30 intersections and 3) within all the sections between the 12 stop signs. The acceleration and the deceleration data were analysed only between the stop sign intersections because of the consistent speed limits on these sections (50 km/hr). The data were then statistically analysed between the age and the gender groups by multivariate analysis of variance/covariance. Results showed that there were age differences for maximum speeds, for all three analyses (i.e., whole road course, all sections, stop sign sections), with the younger drivers having faster speeds than the older drivers. Acceleration results showed that older drivers accelerated over a longer distance than younger drivers, and that older female drivers had less deceleration over a longer distance than younger female and older male drivers. It is concluded that age group differences exist for speed and acceleration, under real-world conditions. The current study's results have implications for road safety because previous studies have concluded that drivers with crashes had higher maximum speeds and accelerations than drivers with no crash record.

Introduction

In general, the main question of this study was "what different driver-induced vehicle movements are exhibited by younger and older men and women with regard to speed, acceleration, and deceleration under real life conditions?". Although driving has been studied for years, most studies have been conducted by examining crash records, using controlled laboratory conditions with simulators, and making determinations by observers inside or outside the vehicle. In this study subjects drove their own vehicles on roads in and around Winnipeg, using a method developed by Porter and Whitton (2002). With this method, Global Positioning System (GPS) coupled with video recording technology simply installed into the subjects' own vehicles enables the quantification of vehicle movement parameters without an observer present.

The relationship between speed and automobile crashes has been extensively studied and is now fairly well understood. The relationship between speed and crashes has been categorized into two distinct patterns; increased mean driving speed (Aljanahi et al., 1999; Keall et al., 2002), and larger variability in traffic speed (Aljanahi et al., 1999; Navon, 2003) with each strongly influencing vehicle crash rate. These two speed factors are "strongly influenced by flow, geometry, speed limit and road quality, and traffic characteristics such as speed and violation level" (Baruya et al., 1999, p.137). Explanations for the relationship between increased speed and increased crash rate may include the reduction of tire-road surface friction, insufficient usage of road signs, road planning, even human biological limitations during driving, or some combination of these, influenced by increased speed. Because there is a strong relationship between driving speed and traffic crashes identified by many researchers, driving speed will become an important subject of the current driving study.

The popular methods that have been used to measure driving speed are: (1) visual speedometer observation (Denton, 1966; Denton, 1969; Rajalin & Summala, 1996; & Godley et al., 2002); (2) Doppler method (radar speed gun and Global Positioning System (GPS)) (Keall et al., 2002; Porter & Whitton, 2002); (3) time-distance calculation (Aljanahi et al., 1999); (4) analog and/or digital measurement of the speedometer and/or sensor recording (Koppa & Hayes, 1976; Boyce & Geller, 2002; Lajunen et al., 1997); (5) survey (Walton & Bathurst, 1998), and (6) computer generated models (Godley et al., 2002; & Navon, 2003). To date none of these measurements has been established as the research "standard", making comparisons between studies difficult.

Complicating most forms of measurement used to date, the calibration of the manufacturer provided speedometer was found to express a lower speed than the actual vehicle speed (Rajalin & Summala, 1996). This is a big concern for the studies which measured vehicle speed using non-calibrated speedometers -- and many of the studies used this popular method (Denton, 1966; Denton, 1969; Rajalin & Summala, 1996; & Godley et al., 2002).

In summary then, measurements in experimental studies of driver behaviour and driver-induced vehicle movements under real world conditions to date have serious limitations as follows: equipment familiarity bias caused by using a "set up" vehicle as opposed to a vehicle familiar to the subjects (Evans & Rothery, 1974; Lundberg & Hakamies-Blomqvist, 2003); short data recording time duration (90 seconds) owing to equipment limitations (Wouters & Bos, 2000); data collection equipment that requires visual reading, which is neither reliable nor precise (Lerner, 2000; Evans & Rothey, 1974); video recording technology to eliminate in-vehicle observer and to measure driver's driving behavior, under unnatural driving conditions without empirical driver-induced vehicle movements (Boyce & Geller, 2002); and unnatural driving conditions, e.g., the visual evaluation of driving performance by a researcher while a subject is proceeding through an experimental driving course (Wood & Mallon, 2001). In short, in the past, it was almost impossible to measure vehicle speed without somewhat controlling the driving environment or having a relatively small sample of empirical information for driving under real world conditions. It is important to overcome these limitations in measuring vehicle movement without controlling the driving environments in order for researchers to record valid and analyzable driver-induced vehicle movements.

In addition to vehicle velocity, a few studies have examined acceleration patterns. In 1975, Rosenbaum concluded that the "motion perception system is tuned to acceleration rather than to constant velocity movement" (p.395). One of the original acceleration-related studies started by investigating vehicle performance (Koppa & Hayes, 1976). More recently, Robertson et al. (1992) focused on driver-vehicle acceleration patterns and found that individuals have unique acceleration patterns which they called "Acceleration signatures". Acceleration signatures consist of longitudinal ("go" and "stop") and lateral ("left" and "right") accelerations. Robertson et. al., (1992) suggested potential future applications of the idea of "acceleration signatures" including driver behavior, traffic engineering, and vehicle design.

Speed and acceleration were later used to measure young male drivers' driving styles by Lajunen et al. (1997). This study utilized "acceleration signatures"

(Robertson et. al., 1992) extrapolating from "individual acceleration signatures" to "group acceleration signatures" between young males with a crash history and those without a crash history. Lajunen et. al. (1997) concluded that young males who had several crashes had higher maximum speeds and lateral accelerations than the group with no crash record. afWåhlberg (2004) investigated the stability of acceleration used as the outcome, and found that there was some relationship between acceleration and crashes. In this study an accelerometer was used to measure a bus' forward/backward (longitudinal) and left/right lateral (centripetal) accelerations.

These previous studies investigating longitudinal (acceleration and deceleration) and lateral (left and right centripetal acceleration) accelerations concluded that differences exist between individuals and groups. All the investigators found strong differences in lateral accelerations, and very weak differences to some tendency of difference in longitudinal accelerations. The results together point to differences in driving performance when individual/categorized groups' acceleration signatures were observed at the corners, turning, during emergency maneuvers, and making quick lane changes under both real road conditions and closed circuit conditions. However, all of the studies that measured acceleration related variables focused on turning/steering at the curvilinear/emergency manoeuver; furthermore, all the accelerations (both longitudinal and lateral) were summed before the analysis. For lateral acceleration, this method may have worked since the research was focused on examining centripetal accelerations, but longitudinal acceleration data was not analyzed well, perhaps because of technological limitations.

To date there has been little research on speed and/or acceleration data under real world road conditions across the lifespan or between genders. Age and gender related differences of the driver are undisputedly important contributions to traffic crashes (e.g., Hu et al., 1998; McGwin & Brown, 1999), and so are important to study when examining the driving behaviour variables of speed and acceleration.

The purpose of this study was to examine driver speed and acceleration patterns as well as potential differences of driver-induced longitudinal vehicle movements--(1) speed, (2) acceleration, (3) deceleration and (4) their related variables--between both age groups and gender groups using GPS data combined with video camera recording technology under real life conditions on the same road course. The hypotheses for age and gender come from will two different conditions. The first condition was the entire road course. It was hypothesized that the younger group and the male group would have higher values of driving speeds (maximum and averaged values). The second section concentrated on the driving sections between stop signed intersections which were the most consistent segments (i.e., 50 Km/hr speed limit, and residential and collector road types). It was hypothesized that both younger (compared to older drivers) and male (compared to female drivers) drivers would display the following differences: (1) higher acceleration (maximum and averaged values), (2) higher deceleration (maximum and averaged values), (3) shorter time of averaged acceleration/deceleration time, (4) shorter distance of averaged acceleration/deceleration distance, (5) shorter time of averaged driving time above 75% of maximum driving speed, and (6) shorter distance of averaged driving distance above 75% of maximum driving speed.

Methods

Subjects. Men and women were recruited into younger (30 to 50 years old) and older adult (70 years and older) groups, with the four groups (i.e., younger men, younger women, older men, and older women) having 13, 12, 13, and 11 subject respectively, for a total of 49 subjects. The age groups were selected based on crash rates which suggest that 30 to 50 year old drivers have the lowest rate relative to their driving exposure, whereas 70 and older drivers have higher relative crash rates (Massie et al., 1995). Inclusion criteria were: a score of less than 25 on a driver self-rating form (Older and Wiser Driver, http://www.gov.mb.ca/shas/driver/index.html); access to a vehicle that the subject regularly drives, possession of a valid driving license, and possession of valid vehicle insurance. On the day of testing, each subject was reminded of the details of the study; all questions and concerns were answered before any testing or equipment setup started. After this briefing, all subjects provided written informed consent as approved by the Education/Nursing Research Ethics Board of the University of Manitoba. Ten dollars was given to subjects to compensate them for gasoline/mileage.

Road Course. For the road course, subjects drove approximately 26 km, on a course that consisted of residential, collector, arterial, and expressway roads. All subjects drove their own vehicles. The following instructions were given to the drivers: (1) drive normally, as you would drive under normal driving conditions, (2) do not use cruise control, (3) go back to the course if you ever get lost. Driving took place during daylight hours and as much as possible on dry roads in good weather conditions. No subjects drove on snow-covered roads.

Equipment. In order to collect empirical driving performance data, the vehicle was equipped with a GeoExplorer II GPS receiver (GEO; Trimble, Sunnyvale, CA), an external antenna with a strong magnet (Trimble, Sunnyvale, CA), a Canon Optura digital video camera (Canon Inc., Tokyo, Japan), and a mono-pod with suction cup (Gruppo Manfrotto, Bassano del Grappa, Italy). For more detailed information see Porter and Whitton (2002).

Digital video camera configurations were set to capture the most information possible from the frontal view of the vehicle. This information from the digital camera was viewed by a blinded observer and was used to determine the presence of another vehicle in the acceleration/deceleration phase.

Data Analyses. Differential corrections were applied to all the data, and base files were provided from the Clay County, Minnesota, Reference Station (http://www.gis.co.clay.mn.us/trshome.htm) and Pathfinder Office 2.51 was used for this technique. The data were analyzed and selected through a custom-programmed data-selecting program (SigmaPlot 8.02) developed by the researcher. Using this program, these data were then selected into 30 segments based on intersections. Each of the driving sections was further divided into the following: 1) main acceleration phases (up to 75% of maximum speed for the section), 2) stabilizing phases (> 75% of maximum speed between the intersections), 3) main deceleration phases (from 75% of maximum speed after the stabilization phase, down to the next intersection), and 4) non-active phases (speeds less than .05 m/s). These data were then analyzed in three categories.

The categories were: (1) the entire data file, (2) all 30 segments, and (3) driving sections that were followed by stop signs only. All variables described earlier in the hypotheses section were selectively analyzed within these three categories. Category (1) “entire driving data” provided the profile of the subjects’ entire driving performance. This data could only be used to analyze the total maximum speed, averaged maximum speed, and total averaged speed over the whole road course, since these variables describe a general impression of driving performance. To examine speed-related patterns for specific segments of the course (Category 2, all 30 segments), we compared the groups’ maximum speeds as well as the number of speeding infractions (> 4 km/hr above the posted speed limit). In order to determine potential group differences for acceleration and deceleration, only the stop sign segments (Category 3) were examined because the rest of the road course had several biases, including different road types, different speed limits (50, 60, 70, 80, and 100 Km/hr), inconsistent traffic signal changes, presence or absence of traffic congestion, and other road users, etc.. These stop sign sections naturally controlled for the type of the road (residential and collector), posted speed limits (50 Km/hr) and, most importantly, for intersections (all the subjects were required to stop, by law, at the stop signs).

Statistical Analyses. In order to test differences between age and gender factors, the following two main types of statistical analyses were used in this study; that is, multivariate 2-way analysis of variance (MANOVA), and multivariate 2-way analysis of covariance (MANCOVA). ANOVA were used to compare specific variables from the MANOVA and MANCOVA results. Pearson's Chi-square was used to analyze the speed infraction data.

Results

The results of the ANOVAs showed that younger drivers drove faster than the older drivers in terms of both maximum (peak) speed and average (20^+) speed ($p = 0.003$ and $p < 0.001$, respectively) over the whole road course. In addition, the ANOVA results for total maximum speed also suggested a strong trend toward a significant gender effect whereby, male drivers drove at a faster maximum speed on the whole road course than female drivers ($p = 0.050$).

Maximum speed analyses by the individual driving sections of the course showed significant age differences by multivariate analysis ($p = .017$) but no gender and age*gender interaction ($p = .896$ and $p =$ 249, respectively) (see Table 1). After dividing the whole road course into first half (driving sections 1 to 13) and second half (driving sections 14 to 30), younger drivers consistently maintained a higher maximum speed (82%, 9 out of 11 sections) (see Table 1). However, in a majority (59 %, 10 out of 17 sections) of the last sections, younger drivers did not have faster maximum speeds than older drivers. Further univariate ANOVA showed: a significant gender difference on section 13 ($p = .04$) a trend to a gender significance difference on section 12 ($p = .08$), a significant age*gender interaction on section 22 ($p = .037$) and a trend of an age*gender interaction on section 28 ($p = .07$).

Non-parametric analyses of the speeding infraction data (i.e., Pearson's Chi-square) displayed a statistically significant age effect for most driving sections indicating that the younger subjects were more likely to be speeding (see Table 2). Additionally in sections 9 and 10 gender differences within the younger group were found to be significant ($p < 0.05$). In both sections 9 and 10, the younger male group had more speed infractions than the younger female group. Due to the small sample size though, most of the expected cell values did not achieve the required quantity of 5.

Results of the multivariate tests on longitudinal acceleration/deceleration related variables showed significance for the main factor of age ($p = .011$), and an age*gender interaction ($p = .044$), but not for gender ($p = .52$). An age effect was found on univariate ANOVA only for average acceleration distance ($p = .003$). The univariate analysis of age*gender was significant for average deceleration distance ($p = .030$) and there were a trend for significance on total maximum deceleration ($p = .070$) and average deceleration time ($p = .053$) (see Table 3). Further analysis of least significant difference (LSD) revealed that: (1) old women had longer average deceleration distance than old men ($p = .013$) and relatively longer averaged deceleration distance than younger women ($p = .092$), (2) younger women had relatively higher total maximum deceleration than younger men ($p = .080$), (3) older women had relatively longer average deceleration time than both old men ($p = .051$) and younger women ($p = .009$).

In this analysis, speed related variables indicated that younger drivers drove faster with averaged maximum speed (47.7 Km/hr) than old drivers (44.3 Km/hr) on 50 Km/hr speed limit zone. As a result, younger drivers drove less time above their 75% of individual driving section's maximum speed (27.2 seconds) than old drivers (30.7 seconds). This speed difference between the age groups was achieved by younger drivers applying acceleration for a longer distance (41.1 meters) than old drivers (37.5 meters).

Table 1. Maximum speed of each section (Mean and Standard Deviation) by age and gender.

Driving section (speed limit Km/hr)	Age differences (p values)	Younger Men $\bar{x} \pm$ S.D. n = 13	Younger Women $\bar{x} \pm$ S.D. n = 12	Older Men $\bar{x} \pm$ S.D. n = 13	Older Women $\bar{x} \pm$ S.D. n = 10	Total n
1 (--)	.582	19.6 ± 2.8	20.3 ± 5.8	17.3 ± 4.4	20.3 ± 9.6	48
2 (50)	*.000*	51.6 ± 4.7	49.8 ± 7.2	45.2 ± 6.2	41.7 ± 8.2	48
3 (50)	--	*43.3 ± 5.9*	*42.4 ± 4.9* *n = 11*	*38.7 ± 7.0* *n = 12*	*35.8 ± 6.9* *n = 7*	*43*
4 (50)	--	*49.7 ± 5.1*	*48.8 ± 5.0*	*43.0 ± 5.1*	*42.6 ± 6.4* *n = 9*	*47*
5 (50)	*.012*	49.0 ± 6.1	47.8 ± 6.9	43.1 ± 5.4	44.9 ± 5.6	48
6 (50)	*.002*	47.8 ± 6.4	47.1 ± 4.7	42.3 ± 6.3	42.3 ± 4.8	48
7 (50)	*.000*	49.4 ± 5.9	51.3 ± 7.7	42.6 ± 5.3	43.6 ± 5.1	48
8 (50)	*.002*	58.9 ± 6.4	59.2 ± 5.7	53.8 ± 4.3	53.9 ± 4.8	48
9 (50)	*.007*	67.5 ± 6.0	64.7 ± 6.0	61.5 ± 3.2	61.5 ± 5.3	48
10 (60)	*.009*	68.9 ± 4.9	67.9 ± 5.4	63.6 ± 2.9	65.3 ± 5.5	48
11 (60)	.134	66.2 ± 6.5	65.9 ± 6.2	61.8 ± 4.1	64.8 ± 6.4	48
12(100)	*.001*	108.1±6.1	102.4±7.6	99.0±5.2	97.5±6.9	48
13(100)	*.012*	108.0±4.9	103.8±6.1	102.7±5.7	99.8±6.2	48
14 (70/60)	*.037*	78.3 ± 4.4	75.5 ± 5.6	73.9 ± 4.3	74.6 ± 4.9	48
15 (50)	.095	54.1 ± 6.3	55.3 ± 7.1	52.9 ± 4.5	51.3 ± 3.5	48
16 (50)	.262	53.2 ± 3.8	55.3 ± 6.9	52.5 ± 5.4	52.3 ± 4.0	48
17 (50)	*.042*	55.6 ± 5.2	56.9 ± 4.3	53.1 ± 4.0	53.8 ± 4.9	48
18 (50)	*.017*	51.2 ± 5.3	50.4 ± 3.7	47.6 ± 3.7	47.4 ± 5.0	48
19 (50)	*.021*	57.2 ± 4.6	55.3 ± 6.6	52.5 ± 3.6	53.8 ± 4.4	48
20 (50)	.414	57.2 ± 3.2	58.4 ± 7.4	55.3 ± 5.1	58.2 ± 6.1	48
21 (50)	*.011*	52.0 ± 3.6	52.4 ± 5.7	47.9 ± 5.4	50.0 ± 3.2	48
22 (50)	.193	49.2 ± 4.1	45.5 ± 5.9	44.7 ± 5.7	46.8 ± 4.5	48
23 (50)	.054	52.5 ± 5.0	52.1 ± 7.0	49.7 ± 4.1	50.0 ± 3.9	48
24 (50)	.222	49.7 ± 6.0	49.5 ± 6.9	46.6 ± 3.3	48.7 ± 3.5	48
25 (80)	.757	89.8 ± 6.5	87.8 ± 5.4	88.1 ± 7.4	88.6 ± 4.9	48
26 (80)	.139	82.0 ± 3.8	77.7 ± 6.7	77.4 ± 5.3	77.0 ± 4.8	48
27 (80)	.317	75.6 ± 5.1	73.5 ± 6.8	73.9 ± 5.0	72.1 ± 4.9	48

Driving section (speed limit Km/hr)	Age differences (p values)	Younger Men $\bar{x} \pm$ S.D. n = 13	Younger Women $\bar{x} \pm$ S.D. n = 12	Older Men $\bar{x} \pm$ S.D. n = 13	Older Women $\bar{x} \pm$ S.D. n = 10	Total n
28 (80)	**.110**	**71.8 ± 4.8**	**68.5 ± 6.2**	**66.0 ± 6.1**	**68.8 ± 6.6**	**48**
29 (60)	**.481**	**68.6 ± 6.6**	**67.0 ± 6.1**	**64.5 ± 6.3**	**67.9 ± 4.9**	**48**
30 (60)	***.026***	**73.5 ± 6.3**	**73.6 ± 8.5**	**67.9 ± 7.1**	**71.1 ± 5.3**	**48**

Note: multivariate test was only significant for age differences ($p = .017$) and gender and interaction were not significant ($p = .896$ and $p = .249$, respectively). -- = no data. Driving section 3 and 4 were not included into the MANOVA since the sample sizes of these sections were smaller than others. For section 3 and 4, many of the subjects made a wrong turn; therefore the sample size is not compatible with the other driving sections.

Table 2. Speed infraction data by driven sections

Intersections	Younger Men count, % of within group data, n=13	Younger Women count, % of within group data, n=12	Older Men count, % of within group data, n=13	Older Women count, % of within group data, n=10	Total # of count, % of section/ total data, n=48
1	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0/0.0%)
2 †	4 (30.8%)	1 (8.3%)	1 (7.7%)	0 (0.0%)	6 (12.5/1.3%)
3 †	0 (0.0%)	0 (0.0%), n = 11	1 (7.7%)	0 (0.0%), n = 7	1 (2.1/0.2%), n = 43
4 ^{*A,†}	1 (7.7%)	3 (25%)	0 (0.0%)	0 (0.0%), n = 9	4 (8.3/0.9%), n = 47
5 †	2 (15.4%)	2 (16.7%)	0 (0.0%)	1 (10.0%)	5 (10.4/1.1%)
6 †	2 (15.4%)	1 (8.3%)	0 (0.0%)	0 (0.0%)	3 (6.3/0.7%)
7 ^{*A,*Af,†}	2 (15.4%)	4 (33.3%)	0 (0.0%)	0 (0.0%)	6 (12.5/1.3%)
8 ^{*A,†}	10 (76.9%)	11 (91.7%)	6 (46.2%)	6 (60.0%)	33 (68.8/7.3%)
9 †, ^{*A,**Am,*Gy}	10 (76.9%)	4 (33.3%)	3 (25.0%)	2 (20.0%)	19 (39.6/4.2%)
10 ^{*Am,*Gy,†}	12 (92.3%)	7 (58.3%)	6 (46.2%)	7 (70.0%)	32 (66.7/7.1%)
11 ^{*Am,†}	9 (69.2%)	5 (41.7%)	4 (30.8%)	5 (10.0%)	23 (47.9/5.1%)

Intersections	Younger Men count, % of within group data, n=13	Younger Women count, % of within group data, n=12	Older Men count, % of within group data, n=13	Older Women count, % of within group data, n=10	Total # of count, % of section/ total data, n=48
12 **[A],**[Am],[†]	10 (76.9%)	5 (41.7%)	1 (7.7%)	1 (10.0%)	17 (35.4/3.8%)
13 **[A],*[Am],[†]	10 (76.9%)	6 (50.0%)	4 (30.8%)	2 (20.0%)	22 (45.8/4.9%)
14 *[Am],[†]	11 (84.6%)	7 (58.3%)	6 (46.2%)	5 (50.0%)	29 (60.4/6.4%)
15*[Af],[†]	7 (53.8%)	8 (66.6%)	3 (23.1%)	2 (20.0%)	20 (41.7/4.4%)
16 [†]	5 (38.5%)	7 (58.3%)	4 (30.8%)	5 (50.0%)	21 (43.8/4.6%)
17 *[A], *[Am],[†]	9 (69.2%)	8 (66.6%)	3 (23.1%)	6 (60.0%)	26 (54.2/5.7%)
18 **[A], *[Am],[†]	4 (30.8%)	2 (16.7%)	0 (0.0%)	0 (0.0%)	6 (12.5/1.3%)
19 *[Am],[†]	10 (76.9%)	5 (41.7%)	5 (38.5%)	7 (70.0%)	27 (56.3/6.0%)
20 *[Am],[†]	11 (84.6%)	6 (50.0%)	6 (46.2%)	6 (60.0%)	29 (60.4/6.4%)
21 [†]	4 (30.8%)	3 (25.0%)	1 (7.7%)	1 (10.0%)	9 (18.8/2.0%)
22 [†]	2 (15.4%)	1 (8.3%)	0 (0.0%)	1 (10.0%)	4 (8.3/0.9%)
23 [†]	5 (38.5%)	4 (33.3%)	2 (15.4%)	1 (10.0%)	12 (25.0/2.7%)
24 *[A] ,*[Am], [†]	4 (30.8%)	3 (25.0%)	0 (0.0%)	1 (10.0%)	8 (16.7/1.8%)
25 [†]	10 (76.9%)	8 (66.6%)	8 (64.5%)	8 (80.0%)	34 (70.8/7.5%)
26 [†]	4 (30.8%)	3 (25.0%)	2 (15.4%)	1 (10.0%)	10 (20.8/2.2%)
27 [†]	0 (0.0%)	1 (8.3%)	0 (0.0%)	0 (0.0%)	1 (2.1/0.2%)
28	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0/0.0%)
29 [†]	8 (61.5%)	6 (50.0%)	6 (46.2%)	7 (70.0%)	27 (56.3/6.0%)

Intersections	Younger Men count, % of within group data, n=13	Younger Women count, % of within group data, n=12	Older Men count, % of within group data, n=13	Older Women count, % of within group data, n=10	Total # of count, % of section/ total data, n=48
30 *[A], *[Am], †	**8 (61.5%)**	**6 (50.0%)**	**2 (15.4%)**	**3 (30.0%)**	**19 (39.6/4.2%)**
total	**174 (38.41%)**	**127 (28.04%)**	**74 (16.34%)**	**78 (17.22%)**	**453 (100%)**

Note: n = Sample size.
*** : p < 0.05 (Pearson Chi-square)**
**** : p < 0.01 (Pearson Chi-square)**
A : Significant age differences
Am : Significant age difference within men
Af : Significant age difference within women
Gy : Significant gender difference within young
† : expected counts were less than 5

Longitudinal acceleration/deceleration related variables when controlled for average maximum speed and average stopped speed, showed significance in multivariate tests for the main factor of age (*p* = 0.032) and age*gender interaction (*p* = 0.023), but not for the main factor of gender (*p* = 0.40). Age differences on univariate ANCOVA analysis were found for four variables. They are total maximum acceleration (*p* = 0.021), average average acceleration (*p* = 0.003), average acceleration time (*p* = 0.021), average acceleration distance (*p* = 0.012), and there was also a trend for average maximum acceleration (*p* = 0.051). The univariate results for age*gender was significant for: (1) total maximum deceleration (*p* = 0.026), (2) average average deceleration (*p* = 0.045), (3) average deceleration time (*p* = 0.005) and (4) average deceleration distance (*p* = 0.040) (see Table 3). Further analysis by LSD post hoc tests showed that: (1) younger women had relatively higher total maximum deceleration values than both older women (*p* = 0.056) and younger men (*p* = 0.090), (2) younger women had higher average average deceleration than older women (*p* = 0.045), (3) older women had longer average deceleration time than older men (*p* = 0.027) and older women had relatively longer average deceleration time than younger women (*p* = 0.052), and (4) older women had longer averaged deceleration distance than older men (p = 0.040) and old women tended to have relatively longer averaged deceleration distance than younger women (*p* = 0.094).

Discussion

For each method of examining driver speed, the results indicated that younger drivers typically drove faster than older drivers, and that there was little effect of gender. Whole course speed analyses results showed that both younger drivers' maximum and averaged whole course speeds were faster than older drivers' maximum speed and averaged whole course speed. Since the whole course data was not controlled for different speed limits, stop sign driving sections were considered because of the consistent speed limit of 50 Km/hr. Even when stop sign driving sections analyses were statistically tested, multivariate tests revealed age differences in driver-induced vehicle speed variables. The maximum speeds in each driving section were investigated and showed that 9 times out of 16 sections (56 %), younger drivers had faster speeds than older drivers.

The speed infraction data revealed that most of the statistical differences were between age groups. Younger drivers drove faster than the speed limits more than the older drivers. Younger male drivers had more (174) infractions than both younger female drivers (127) and older female drivers (74), and younger female drivers had more infractions than older male drivers (78). Younger drivers had almost a two-fold increase in the number of speed infractions (301) compared to older drivers (152). Overall, younger drivers were twice as likely to go over the speed limit as older drivers, although there were several instances of older drivers speeding, contrary to the stereotype. A trend toward a gender difference in maximum speed in the two highway sections (12 and 13) was shown. These results seem to suggest that male drivers tend to drive faster than female drivers, only on the highest speed roadways.

Table 3. Age and gender comparisons of univariate ANOVA / ANCOVA results for the stop sign sections of the course. Only deceleration variables with significant effects are shown.

Variables		YM n=13	YF n=12	OM n = 13	OF n = 10
		MANOVA (A) $\bar{x}$ ± SD			
		MACOVA (C) $\bar{x}$ ± SE			
Total max dec (m/s^2)	A	_-3.8 ±0.8_	_-4.5 ±1.3_	-4.2 ±0.7	-3.9 ±0.8
	C	_-3.6 ±0.2_	_-4.3 ±0.2_	-4.4 ±0.2	_-4.0 ±0.3_
Ave ave dec (m/s^2)	A	-1.7 ±0.3	-1.8 ±0.2	-1.7 ±0.2	-1.6 ±0.3
	C	-1.6 ±0.1	_-1.7 ±0.1_	-1.8 ±0.1	_-1.7 ±0.1_
Ave dec time (sec.)	A	6.6 ±0.9	_6.3 ±1.0_	_6.2 ±0.8_	_7.0 ±1.1_
	C	6.7 ± 0.2	_6.4 ± 0.2_	6.0 ±0.2*	_7.1 ±0.3*_
Ave dec dist (meters)	A	34.5 ± 3.6	_33.3 ± 8.1_	31.2 ±5.2*	_37.5 ±5.3*_
	C	34.0 ± 1.7	_32.9 ± 1.7_	31.7 ±1.7*	_37.9 ±1.9*_

Note: YM: Younger male, YF: Younger Female, OM: Old Male, and OF: Old Female. Significant multivariate age*gender difference were found on both MANOVA (A) (p = 0.044) and MANCOVA (C) (p = 0.023) were found. Italic numbers with (*) represent statistical significance ($p < 0.05$) and Italic numbers represent ($0.05 \leq p < 0.10$)

In terms of speed related-variables, younger drivers drove faster than older drivers, consistent with previous studies (e.g., Porter & Whitton, 2002; McGwin & Brown, 1999; Boyce & Geller, 2002), and younger drivers had more speed infractions than older drivers (e.g., Porter & Whitton, 2002; McGwin & Brown, 1999). In the current study, even though older drivers did not always / consistently drive slower than younger drivers on the road course, and did in fact exceed the speed limit in certain circumstances, it is possible to conclude that older drivers' driving speeds were slower than younger drivers. Previous studies indicate that both (1) "maximum speed seemed to be a convenient and robust measure of a safe driving style" (e.g., Lajunen et al, 1997, p. 3) and (2) vehicles which are slower than the mean traffic speed are more prone to traffic crash(es) (e.g., Buruya et al., 1999). In light of the latter findings and the current results, it is possible that older drivers are more likely to be involved in crash(es) because of speed discrepancies in comparison to other drivers on the road, whereas the younger drivers, particularly younger male drivers may be more prone to crashes involving higher speeds on highways. Given the trend toward significant gender differences in speed (i.e., male drivers tend to driver faster than female drivers), support can be found for previous research conclusions such as male drivers have more loss of control crashes than female drivers (Tavris et al., 2001; Mayhew et al., 2003), and also male drivers were more often involved in single-vehicle crashes (Mayhew et al., 2003).

Results of the stop sign section showed non-significant age differences on absolute (non-controlled) acceleration related variables except for acceleration distance, which showed that older drivers had shorter acceleration distance than younger drivers. Younger drivers likely employed a longer acceleration distance compared to older drivers in order to reach a faster cruising speed than older drivers.

The current results of the acceleration data analysed by ANOVA did not show any significant differences for age and gender. This finding was consistent with Porter and Whitton (2002) in that younger (20 to 29), middle-aged (30 to 64), and older drivers (65 years old and older) had statistically non-significant acceleration differences for 3 of the 4 variables examined. However, acceleration time was significantly shorter in the younger subjects compared to the middle aged and older subjects (Porter & Whitton, 2002). Because the age groups of the subjects were different, further comparisons of the data between the two studies are difficult.

Since acceleration is greatly affected by speed, age group differences in speed may have affected acceleration analyses. Therefore, acceleration data needed to be controlled for speed. ANCOVA analyses successfully removed age differences due to started/stopped speed and driving speed from acceleration. This driven speed adjustment allowed the following variables to become statistically significant: total maximum acceleration, averaged average acceleration, and total acceleration distance. In addition, two variables, total acceleration time and average maximum acceleration, showed a tendency toward significance. The results of these relative value tests indicated that older drivers had a higher amount of acceleration than younger drivers when both groups reached the same driving speed. In other words, when the influence of speed effects were removed, older drivers applied greater acceleration over a shorter acceleration distance and shorter acceleration time than younger drivers. Unfortunately, an intensive search of previous driving studies revealed that none of the studies methodologically / or statistically controlled the driving speed from the acceleration values. Since there were no previous studies concerning the relative values of acceleration, possible explanations are difficult to determine. However, we know that since there are no manufacturer-installed instruments which give acceleration readings, drivers cannot judge their acceleration rates through instrument readings, drivers must judge their optimum acceleration rates from processed information which Denton (1969) called “sensory information”. Therefore this relative acceleration may hold the key to understanding driver-induced vehicle movements. Either older drivers adjust their acceleration to be similar to the majority of drivers even though they reach a slower driving speed, or they are affected by age-related changes which affect their ability to process information and perform movements in a controlled fashion. This finding certainly requires further study.

Absolute deceleration values (ANOVA) showed that younger women tended to have significantly higher peak deceleration values (i.e., total maximum deceleration) in stop sign driving sections than younger men. When deceleration time and distance were compared for age and gender, older women decelerated over a longer distance and longer time than both younger women (with a tendency toward significance) and younger men (both time and distance with a tendency toward significance). Older women spent a longer time (tendency toward significance) and distance in the deceleration phase than the other groups, except for younger men.

When driving speed was controlled (ANCOVA), younger women had relatively greater deceleration values than older female drivers (i.e., total maximum deceleration and average average deceleration) and younger male drivers (i.e., total maximum deceleration). Results of deceleration time and distance showed that older women decelerated over a longer time and longer distance than older men and younger women (tendency toward significance). In short, younger women had more deceleration for shorter times and shorter distances than older women when driving speeds and stopping speed were taken into consideration.

Additionally, when absolute values were controlled for started/stopped/reached speed, all the deceleration (i.e., total maximum deceleration, average maximum deceleration, and average average deceleration) values shifted according to age group, meaning that younger drivers' mean values decreased but older drivers' mean values increased systematically. This was expected, mirroring acceleration phase shifts. Finally, it is important to notice that deceleration distance and deceleration time were only affected a minimal amount by driving speed.

As in the acceleration section, there were no previous studies examining the relative values of deceleration. However, we can assume that comparing the relative values of deceleration may explain how drivers process sensory system information. This relative deceleration is important in understanding driver-induced vehicle movements. There has been at least one previous study which found that, in emergency braking situations, older drivers had the same perception reaction time as younger drivers (Lerner, 2000). However, Lerner (2000) further suggested that, under natural conditions, age differences in perception reaction time may appear. The current study found that under natural conditions older women are more likely to decelerate over a longer distance for a relatively longer time.

The statistical results from both acceleration and deceleration distances suggested that they were the least influenced by started/stopped and reached speeds among the variables tested in current study. Even though Robertson et al. (1992) and Lujunen et al. (1997) established that specific groups of drivers have their own pattern of longitudinal and lateral accelerations, they did not consider the start, stop, and reached speed of the tested vehicles. Results from the current study strongly suggest that longitudinal acceleration rates were influenced by start, stop, and reached speeds, and could not be used to examine signatures. However, in the present study acceleration and deceleration distance may also be expressed in a similar manner to Robertson et al. (1992) and Lujunen et al. (1997)'s "acceleration signature,". This approach to expressing longitudinal acceleration will reduce the bias from the variable driven speed of the drivers. This longitudinal acceleration distance approach successfully demonstrated the age differences in the acceleration phase (that younger drivers have a longer acceleration distance than old drivers), and in the deceleration phase (old female drivers have longer deceleration distance than younger female drivers and old male drivers).

Conclusion

This current study was able to conclude that age group differences and age*gender interactions in driver-induced vehicle movement(s) exist. The hypotheses about the existence of age differences--specifically that younger drivers will have higher values of acceleration and speed related variables than older drivers--were partially supported. Younger drivers did drive faster than older drivers, on average, however, the acceleration phase did not show the anticipated findings, in that there were no major differences between the groups with the uncontrolled data. In addition, unexpectedly, the deceleration phase showed an age*gender interaction; older female drivers had lower decelerations over longer deceleration distances than younger female drivers. Older male drivers showed a similar tendency. There was a tendency for older male drivers to show similar deceleration over younger male drivers.

When simple observations of driver-induced vehicle movement(s) were statistically controlled for driver's start, stop, and reached speed, the results were almost opposite to the hypothesized results. Older drivers displayed higher values of acceleration over shorter acceleration distances and shorter acceleration times than younger drivers in order to reach same driving speed from the same starting speed. However, the deceleration phase showed that older women had lower deceleration values over longer deceleration time distances and longer deceleration times than younger women; there was a tendency for the same in older men. In other words, when driving speeds were statistically controlled, acceleration showed age differences; however, the deceleration phase showed only older female drivers being different than younger female drivers. Older male drivers showed a similar non-significant tendency.

The results of the current study showed that older drivers drove slower than younger drivers which can be expressed as "older drivers are slow drivers" instead of "younger drivers are fast drivers" if younger drivers are acknowledged as the reference group on the road (despite younger drivers having more speeding infractions). In addition, as a byproduct of significantly different acceleration / deceleration distances (from examining age differences in acceleration, speed, and age*gender interaction) and in deceleration in driver-induced vehicle movements a unique pattern for each group similar to the "acceleration signature" of Robertson (1992) may be used to express driver-induced vehicle movements characteristic of each age/gender group.

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