Intraindividual Variability in Driving Simulator Parameters of Healthy Drivers of Different Ages

Alexandra Economou[a]

Ion Beratis[b]

Eleonora Papadimitriou[c]

George Yannis[d]

Sokratis G. Papageorgiou[b]

[a]Department of Psychology, School of Philosophy, National and Kapodistrian University of Athens, Athens, Greece.

[b]1st University Department of Neurology, Eginiteion Hospital, National and Kapodistrian University of Athens, Athens, Greece.

[c]Delft University of Technology, Faculty of Technology, Policy and Management, Delft, The Netherlands.

[d]School of Civil Engineering, Department of Transportation Planning and Engineering, National Technical University of Athens, Athens, Greece

Correspondence:

Alexandra Economou, PhD.
Department of Psychology, School of Philosophy
The National and Kapodistrian University of Athens
Panepistimiopolis, Ilissia 157 84
Athens, Greece
e-mail : aoikono@psych.uoa.gr

Abstract

Intraindividual variability is a fundamental behavioural characteristic of aging but has been examined to a very limited extent in driving. This study investigated intraindividual variability in driving simulator measures in healthy drivers of different ages using the coefficient of variation (COV) as a variability measure. Participants were healthy volunteers who were regular drivers, who were divided into a “young” group, a “middle-aged” group, and an “old” group. They drove in two environments (rural, 72 drivers; urban, 60 drivers), under conditions of moderate and high traffic load, without and with distraction (conversation). Significant differences in COV were observed in the rural condition for headway distance and lateral position as a function of traffic load, with high traffic (without and with distraction) resulting in increased COV of headway and decreased COV of lateral position. Significant differences in COV were observed in the urban condition for headway distance only, with high traffic (without and with distraction) resulting in increased COV of headway. No age effects were found for any of the driving conditions. The results indicate that traffic load affected headway distance and lateral position in opposite directions in all three age groups: high traffic resulted in increased variability of headway in both rural and urban conditions but in decreased variability of lateral position in the rural conditions compared to moderate traffic irrespective of distraction. The study indicates that driving conditions affect the intraindividual variability of driving measures in selective ways, which may be linked to the extent of automatization of the driving variables.

Keywords: Driver behaviour, Age, Traffic load, Distraction, Skilled performance

1. Introduction

The study of age-related changes has reflected certain assumptions about the stability of the behaviour being studied. Comparisons of mean level performance across different age groups or examinations of average changes in performance over time make the assumption either that the behaviours of interest are stable over time or that the trajectory of change is similar for all persons (Hultsch, MacDonald, & Dixon, 2002; Hultsch, Strauss, Hunter, & MacDonald, 2008). Intraindividual variability is a signal in its own right rather than error, as traditional views of psychological measurement assume, and can be measured reliably. It is systematically associated with personal characteristics such as age, and with performance outcomes such as changes in cognitive functioning or central nervous system compromise (Hultsch et al., 2008).

Hultsch and colleagues (2002) have defined three types of variability: variability in relation to persons, in relation to measures, and in relation to occasions. Interindividual variability or diversity refers to differences between persons on a single task on a single occasion. Inraindividual variability or dispersion refers to variability associated with measuring a single person once on multiple tasks, or on multiple conditions of a single task. Intraindividual variability or inconsistency refers to the variability of measuring a single person on a single task on multiple occasions.

Studies of intraindividual variability have typically employed simple and choice reaction time (RT) tasks to measure it. These studies have shown that intraindividual variability across tasks and across time is a fundamental behavioural characteristic of aging (Anstey, 1999; Bielak, Cherbuin, Bunce, & Anstey, 2014; Christensen, Mackinnon, Korten, Jorm, Henderson, & Jacomb, 1999; Deary & Der, 2005; Dixon, Garrett, Lentz, MacDonald, Strauss, & Hultsch, 2007; Hultsch, Hunter, MacDonald, & Strauss, 2005; Hultsch et al., 2002; Hultsch & MacDonald, 2004; Vasquez, Binns, & Anderson, 2016; review by Haynes, Bauermeister & Bunce, 2017a). Inconsistency correlated negatively with cognitive measures (Hultsch et al., 2002) and errors (Haynes, Bauermeister & Bunce, 2017b), was associated with executive functioning performance (Vasquez et al., 2016), and predicted cognitive decline and mortality in older adults (Batterham, Bunce, Mackinnon, & Christensen, 2014; Haynes et al., 2017a; Lövdén, Sching, & Lindenberger, 2007; Yao Stawski, Hultsch, & MacDonald, 2016), whereas mean RT did not over and above the effects of age, gender and health (Batterham et al., 2014).

Individuals who were more variable on RT tasks were more prone to making errors of omission on higher order visual search tasks and this relationship was stronger in older individuals. The errors may be related to inattention, with implications for visual processing errors in safety-critical situations such as driving (Haynes et al., 2017b). Indeed, the greater intraindividual variability in RT of older individuals, as measured by the intra-individual standard deviation (ISD), was linked to a Gaussian component reflecting attentional lapses (Vasquez et al., 2016).

The ISD can be computed across tasks to examine dispersion, or across time (trials or occasions) to examine inconsistency. Inconsistency may be a characteristic of slower individuals regardless of age, however, and the greater intraindividual variability of older people may be due to their greater RT (Myerson, Robertson & Hale, 2007). To control for such potential confounds the coefficient of variation (COV) has been used, which expresses the *SD* as a percentage of mean performance level (intraindividual *SD*/intraindividual *M*) and permits variability comparisons across different variables or groups (Haynes et al., 2017a; Hultsch & MacDonald, 2004). The COV takes mean level of performance into account, which has been shown to affect the standard deviation, as larger *SD*s tend to be associated with larger means (Hale, Myerson, Smith, & Poon, 1988). Intraindividual variability can be also adjusted for simple RT mean by linear regression, with the saved standardized residuals as the dependent variable (e.g., Deary & Der, 2005), or by regressing the RT on age (e.g., Hultsch et al., 2002).

Cognitive load and task complexity are associated with greater increases in variability in middle aged and older adults (e.g., Bielak et al., 2014; Bielak, Hultsch, Strauss, MacDonald, & Hunter, 2010; Dixon et al., 2007). When intraindividual variability in a cognitively more demanding RT task was included, it was an even stronger predictor of cognitive impairment in “mid-old” and “old-old” participants (Dixon et al., 2007). Similarly, intraindividual variability in more cognitively challenging tasks was particularly sensitive to longitudinal changes in cognitive ability in community-dwelling older adults (Bielak et al., 2010). When different age groups were compared, choice RT showed significant increases in variability over time for adults 40 and older and especially 60 and older (Bielak et al., 2014).

Simulated driving lends itself to the study of intraindividual variability due to the continuous nature of simultaneous data collection. Very few studies have examined intraindividual variability in driving performance, however. Those studies examining the effect of cognitive load and driving complexity on driving using variability measures have only used *SD*, typically of lateral position (e.g., Cantin, Lavallière, Simoneau, & Teasdale, 2009; Fofanova & Vollrath, 2011; Irwin, Monement, & Desbrow, 2015). Extrapolating from studies on intraindividual variability in aging using RT, the COV may be of potential importance in the investigation of driving performance in aging and cognitive decline.

In the only study that examined intraindividual variability in driving simulator measures that we are aware of, young and old drivers were compared on headway and lateral lane position, using the standard error of the regression line for each measure (Bunce, Young, Blane, & Khugputh, 2012). Older age and driving condition (residential, urban, motorway) were associated with greater driving inconsistency, with the older group exhibiting greater inconsistency in the ability to maintain a safe distance from the preceding vehicle and in side to side movement in road position relative to the young group in the faster motorway condition.

Both cognitive load and task complexity have been shown to affect driving performance in simulated driving. Cognitive load includes use of distraction, with physical and cognitive distraction affecting a number of driving measures in simulated driving (Alosco, Spitznagel, Fischer, Miller, Pillai, Hughes, & Gunstad, 2012; Cantin et al., 2009; Cuenen, Jongen, Brijs, Brijs, Lutin, Vlierden, & Wets, 2016; Hornberry, Anderson, Regan, Triggs, & Brown, 2006; Irwin et al., 2015; Rumschlag, Palumbo, Martin, Head, George, & Commissaris, 2015; Stavrinos et al., 2013). Task complexity includes traffic volume, with lower traffic volumes resulting in elevated exiting speed and deceleration from high-speed lanes to low-speed ramps (Calvi, Benedetto, & De Blasiis, 2012); and complexity of driving context, with older drivers showing longer reaction times and/or slower speed in complex contexts (Cantin et al., 2009; Hornberry et al., 2006). Intraindividual variability has not been examined as a function of cognitive load and has been examined to a very limited extent as a function of driving condition.

The aim of the present study was to examine intraindividual variability in driving simulator measures in healthy drivers of different ages. This is an area that is underexplored yet may offer important insights into driving performance changes with age and condition. We examined intraindividual variability or inconsistency of the same continuous measures in different driving scenarios and conditions. Extrapolating from the studies on aging reviewed, we hypothesized that (a) older drivers would show greater intraindividual variability compared to younger drivers; (b) driving conditions with greater task complexity due to high traffic load would result in greater intraindividual variability than driving conditions with smaller task complexity due to lower traffic load; (c) driving conditions with greater cognitive load due to use of distraction would result in greater intraindividual variability than driving conditions with smaller cognitive load due to no distraction.

2. Method

2.1. Participants

Research participants were healthy unpaid volunteers over the age of 20 who were active drivers at the time of the study, with a valid driver's license. Participants were recruited by the investigators for the DISTRACT study (full title "Analysis of causes and impacts of driver distraction"), a driving simulator experiment which examined the influence of participant and driving variables on the driving performance of healthy participants of different ages, and neurology patients with diseases affecting cognition (see https://www.nrso.ntua.gr/geyannis/res/rn56-distract-causes-and-impacts-of-driver-distraction-a-driving-simulator-study-in-the-framework-of-the-research-programme-thalis-for-the-ministry-of-education-lifelong-learning-and-religious-affair/ for information on the project and relevant publications). The study began in July of 2012. The drivers of the present study were selected out of a total of 90 control drivers on the basis of completion of the four rural and the four urban driving conditions that were investigated. Seventy-two drivers 22-78 years of age (35 women) completed all four rural conditions, and 60 drivers 22-78 years of age (27 women) completed all four urban conditions. Because the rural conditions were always presented first (see following section), 56 out of the 60 drivers of the urban conditions were the same as the drivers of the rural conditions.

The drivers were divided into three age groups for each driving environment. Of the 72 drivers who completed all four rural driving conditions 28 comprised the "young" group (*M* = 27.25, *SD* = 3.44, 22-34 years), 27 the "middle-aged" group (*M* = 46.85.25, *SD* = 4.88, 38-53 years) and 17 the "mid-old" group (*M* = 66.00, *SD* = 7.23, 55-78 years). Of the 60 drivers who completed all four urban driving conditions 26 comprised the "young" group (*M*

= 26.92, *SD* = 3.27, 22-34 years), 22 the “middle-aged” group (*M* = 47.18, *SD* = 4.93, 38-53 years) and 12 the “mid-old” group (henceforth “old” group) (*M* = 65.33, *SD* = 8.06, 55-78 years).

Table 1.

Participation in the driving conditions by age group

Age group	R1	R2	R3	R4	U1	U2	U3	U4
22-34	28 (28)	28 (28)	28 (28)	28 (28)	26 (26)	26 (26)	26 (26)	26 (26)
38-53	27 (28)	27 (29)	27 (30)	27 (29)	22 (26)	22 (25)	22 (24)	22 (24)
55-78	17 (28)	17 (29)	17 (21)	17 (24)	12 (20)	12 (18)	12 (16)	12 (16)
Total	72 (84)	72 (86)	72 (79)	72 (81)	60 (72)	60 (69)	60 (66)	60 (66)

R: Rural; U: Urban; 1: Moderate traffic, no distraction; 2: High traffic, no distraction; 3: Moderate traffic, distraction (conversation); 4: High traffic, distraction (conversation). Numbers indicate number of participants per age group per condition, who completed all four R and all four U conditions and were included in the analyses. In parentheses are the numbers of participants who completed each of the driving conditions.

Table 1 shows the percent of participants who completed all four driving conditions from the number of participants who completed each condition. Of the “young” participants 100% completed all four rural and all four urban driving conditions. Of the “middle-aged” participants between 90%-96% completed all four rural and between 85%-92% all four urban driving conditions. Of the “old” participants between 59%-81% completed all four rural and between 60-75% all four urban driving conditions. The percentages show higher attrition rates in the “old” group relative to the other two groups, which were due to simulator sickness.

2.2. Materials and procedure

A quarter-cab Foerst FPF simulator (3 LCD wide screens, 42”, full HD: 1920 x 1080 pixels-total field of view 170 degrees validated against a real driving environment) was employed in the study. Hand shift gears were used by all the participants. The study design and procedure have been explained elsewhere (Yannis *et al*., 2013). Briefly, after a 5-10-minute practice session, participants drove on a two-lane rural road and on urban streets with multiple lanes. Driving environment (rural-urban), traffic flow (moderate-high) and presence/type of distractor (no distractor, conversation, mobile phone use) were within-subject variables. The drivers drove in two separate sessions of approximately 20 minutes each, with each session corresponding to a different driving environment; a break was introduced between the two sessions to reduce simulator sickness. Traffic flow and distractor were fully counterbalanced across participants for each driving environment. The rural drive was always presented first, because it was shown in the pilot study that it resulted in fewer incidents of simulator sickness. A single factorial design including driving environment would have entailed many more combinations in the factorial design, with sample power requirements that would not be feasible. Moreover, it would not permit direct comparisons of the corresponding conditions due to differences in the actual driving environments. For example, rural roads were single carriageway with a 3 m lane width, whereas urban roads were for the most part dual carriageway, with a 3.5 m lane width, precluding the direct comparison of lateral position.

Within each driving environment, moderate traffic was calculated as follows: ambient vehicle arrivals were drawn from a Gamma distribution with mean = 12 s and variance = 6 s corresponding to an average traffic volume Q = 300 vehicles/hour; high traffic was calculated as follows: ambient vehicle arrivals were drawn from a Gamma distribution with mean = 6 s and variance = 3 s corresponding to an average traffic volume Q = 600 vehicles/hour.

Distraction for each driving environment involved conversation with a passenger, a research associate of the study, the same one for all participants. Conversation was casual and included topics involving one’s family, personal interests, the news, etc.

In the rural driving environment participants drove on a 2.1 km- long, single carriageway rural route of 3 m lane width with zero gradient and mild horizontal curves. In the urban driving environment participants drove on a 1.7 km-long urban route of 3.5 m lane width, at its largest part dual carriageway, separated by guardrails. Narrow sidewalks, commercial uses and parking were present at roadsides. Two traffic-controlled junctions, one stop-junction and one roundabout were present along the route.

In this study, the following data were utilized: from the rural (R) driving conditions, moderate traffic without and with distraction (conversation) (R1 & R3), and high traffic without and with distraction (conversation) (R2 & R4); from the urban (U) driving conditions, moderate traffic without and with distraction (conversation) (U1 & U3), and high traffic without and with distraction (conversation) (U2 & U4). The four specific conditions were selected because more participants completed them relative to the remaining two conditions, which involved mobile phone use (in moderate and high traffic). Of the “middle-aged” participants, 53%-57% completed the two rural conditions with mobile phone use and 50%-54% completed the two urban conditions with mobile phone use. Of the “old” participants, 45%-48% completed two rural conditions with mobile phone use and 30%-35% completed the two urban conditions with mobile phone use. Refusal to drive using a mobile phone was the main reason for the low completion rates. None of the participants had had any prior experience with a driving simulator.

Participants underwent a structured interview, a comprehensive neurological and behavioral assessment and clinical history evaluation, a test of visual acuity, and detailed neuropsychological assessment and personality testing.

The research complied with the American Psychological Association Code of Ethics and was approved by the IRB of Attikon University General Hospital. All participants provided written informed consent and were given brief written feedback on their driving simulator performance upon request.

2.3. Data collection and analysis

Continuous vehicle data, obtained from the driving simulator every 17 msec, were recorded. The following driving simulator measures were selected based on their usefulness in past research studies and their representing both longitudinal and lateral control measures.

Speed-position measures

Average speed: average speed of the vehicle in km.

Headway average: average distance of the vehicle from the lead vehicle in m.

Lateral position: average position from the right road border in m.

Variability measures

Average speed variability: individual *SD* of average speed in km.

Headway variability: individual *SD* of headway average in m.

Lateral position variability: individual *SD* of lateral position average in m., a measure of variability in lane position.

The coefficient of variation (COV) was used as a within-person variability metric. It was calculated as the raw intraindividual *SD* divided by the raw intraindividual *M* to provide a measure relative to the driver's level of performance for: speed, headway distance, and lateral position (after Haynes, Bauermeister, & Bunce, 2017b).

3. Results

3.1. Mean differences in performance across the age groups and driving conditions

Three-way repeated measure analyses were conducted, examining the speed-position and variability measures separately for the rural and urban conditions. Traffic load (2 levels) and distraction (2 levels) were within-subject variables and age group (3 levels) was between-subject variable. The “young” group was the reference group for the age group comparisons.

In the rural conditions there was a large effect of traffic load for all the variables studied (speed, headway, lateral position, *SD* speed, *SD* headway, *SD* lateral position) (Table 2). The high traffic conditions resulted in lower speed, smaller *SD* of speed, shorter headway, smaller *SD* of headway, larger lateral position, and smaller *SD* of lateral position, compared to the moderate traffic conditions. There was a small to medium effect of distraction for *SD* of headway only: conditions of no distraction had larger *SD* of headway than conditions of distraction. There was a medium to large effect of age group for all the variables except for lateral position and *SD* of lateral position, with the “old” group showing lower speed and *SD* of speed, and larger headway and *SD* of headway than the “young” group. A medium traffic load by age interaction was found for speed, with smaller differences in speed between moderate and high traffic in the “old” group. A traffic load by distraction by age interaction showed a differentiation of the effect of distraction as a function of traffic load in the different age groups. A small to medium traffic load by distraction interaction was found for *SD* of lateral position: in moderate traffic the *SD* of lateral position was higher in the no distraction relative to the distraction condition, whereas in high traffic it was lower in the no distraction relative to the distraction condition.

Table 2

Analyses of the driving measures by traffic load, distraction, and age group in the rural condition

Variable	Traffic load	Distraction	Age	Traffic load by distraction	Traffic load by age	Distraction by age	Traffic load by distraction by age
Speed	F(1,69)=66.08 $p < .001$ $\eta_p^2=.49$ moderate > high	F(1,69)=0.53 $p > .05$	F(2,69)=7.69 $p = .001$, $\eta_p^2=.18$ old < young	F(1,69)=2.00 $p > .05$	F(2,69)=4.70 $p = .012$, $\eta_p^2=.12$	F(2,69)=1.64 $p > .05$	F(2,69)=6.33 $p = .003$, $\eta_p^2=.16$
Headway	F(1,69)=685.60 $p < .001$, $\eta_p^2=.91$ moderate > high	F(1,69)=0.02 $p > .05$	F(2,69)=7.17 $p = .001$, $\eta_p^2=.17$ old > young	F(1,69)=0.08 $p > .05$	F(2,69)=2.06 $p > .05$	F(2,69)=1.80 $p > .05$	F(2,69)=2.77 $p > .05$
Lateral position	F(1,69)=170.88 $p < .001$, $\eta_p^2=.71$ moderate < high	F(1,69)=2.16 $p > .05$	F(2,69)=2.86 $p > .05$	F(1,69)=0.11 $p > .05$	F(2,69)=0.66 $p > .05$	F(2,69)=0.19 $p > .05$	F(2,69)=0.06 $p > .05$

SD speed	$F(1,69)=27.51$ $p < .001$, $\eta_p^2=.29$ moderate > high	$F(1,69)=0.24$ $p > .05$	$F(2,69)=4.36$ $p = .017$, $\eta_p^2=.11$ old < young	$F(1,69)=1.41$ $p > .05$	$F(2,69)=2.71$ $p > .05$	$F(2,69)=2.77$ $p > .05$	$F(2,69)=2.99$ $p = .057$
SD headway	$F(1,69)=288.85$ $p < .001$, $\eta_p^2=.81$ moderate > high	$F(1,69)=5.88$ $p = .018$, $\eta_p^2=.08$ no distraction > conversation	$F(2,69)=8.08$ $p = .001$, $\eta_p^2=.19$ old > young	$F(1,69)=0.20$ $p > .05$	$F(2,69)=1.23$ $p > .05$	$F(2,69)=2.53$ $p > .05$	$F(2,69)=2.65$ $p > .05$
SD lateral position	$F(1,69)=38.07$ $p < .001$, $\eta_p^2=.36$ moderate > high	$F(1,69)=0.43$ $p > .05$	$F(2,69)=2.34$ $p > .05$	$F(1,69)=5.86$ $p = .018$, $\eta_p^2=.08$	$F(2,69)=2.85$ $p > .05$	$F(2,69)=0.95$ $p > .05$	$F(2,69)=2.83$ $p > .05$

Age reference category: young group.

In the urban conditions there was large effect of traffic load for speed, headway, and *SD* of headway (Table 3). The high traffic conditions resulted in lower speed, shorter headway and smaller *SD* of headway compared with the moderate traffic conditions. There was a small to medium effect of distraction for *SD* of headway only: conditions of no distraction had larger *SD* of headway than conditions of distraction. There was a medium to large effect of age group for speed, headway, lateral position, and *SD* of speed, with the “old” and “middle-aged” groups showing lower speed than the “young” group; the “old” group showing larger headway than the “young” group; and the “middle-aged” and “old” groups showing larger lateral positions than the “young” group. A medium traffic load by distraction interaction was found for *SD* of headway: in high traffic the *SD* of headway in the no distraction was higher relative to the distraction condition, whereas in moderate traffic there was no difference between the two distraction conditions. Medium traffic load by age interactions were found for speed and headway: the “old” group showed lower speed and smaller headway in high traffic relative to moderate traffic. A medium traffic load by distraction by age interaction for headway showed a differentiation of the effect of distraction as a function of traffic load in the different age groups.

Table 3

Analyses of the driving measures by traffic load, distraction, and age group in the urban condition

Variable	Traffic load	Distraction	Age	Traffic load by distraction	Traffic load by age	Distraction by age	Traffic load by distraction by age
Speed	F(1,57)=49.92 $p < .001$ $\eta_p^2=.47$ moderate > high	F(1,57)=0.41 $p > .05$	F(2,57)=11.49 $p < .001$, $\eta_p^2=.29$ middle-aged <young, old < young	F(1,57)=3.24 $p > .05$	F(2,57)=3.60 $p = .034$, $\eta_p^2=.11$	F(2,57)=0.09 $p > .05$	F(2,57)=0.75 $p > .05$
Headway	F(1,57)=188.29 $p < .001$, $\eta_p^2=.77$ moderate > high	F(1,57)=2.24 $p > .05$	F(2,57)=3.63 $p = .033$, $\eta_p^2=.11$ old > young	F(1,57)=0.00 $p > .05$	F(2,57)=3.26 $p = .046$, $\eta_p^2=.10$	F(2,57)=1.65 $p > .05$	F(2,57)=4.31 $p = .018$, $\eta_p^2=.13$
Lateral position	F(1,57)=1.68 $p > .05$	F(1,57)=0.78 $p > .05$	F(2,57)=4.00 $p = .024$, $\eta_p^2=.12$ middle-aged > young old > young	F(1,57)=0.63 $p > .05$	F(2,57)=0.92 $p > .05$	F(2,57)=2.11 $p > .05$	F(2,57)=0.55 $p > .05$

SD speed	F(1,57)=1.86 $p > .05$	F(1,57)=1.25 $p > .05$	F(2,57)=4.92 $p = .011$, $\eta_p^2=.15$ old < young	F(1,57)=1.01 $p > .05$	F(2,57)=1.33 $p > .05$	F(2,57)=0.60 $p > .05$	F(2,57)=0.40 $p > .05$
SD headway	F(1,57)=67.08 $p < .001$, $\eta_p^2=.54$ moderate > high	F(1,57)=5.44 $p = .023$, $\eta_p^2=.09$ no distraction > conversation	F(2,57)=2.43 $p > .05$	F(1,57)=5.35 $p = .024$, $\eta_p^2=.09$	F(2,57)=2.00 $p > .05$	F(2,57)=0.31 $p > .05$	F(2,57)=0.35 $p > .05$
SD lateral position	F(1,57)=0.49 $p > .05$	F(1,57)=0.21 $p > .05$	F(2,57)=1.54 $p > .05$	F(1,57)=0.56 $p > .05$	F(2,57)=0.50 $p > .05$	F(2,57)=1.93 $p > .05$	F(2,57)=0.36 $p > .05$

Age reference category: young group.

3.2. Coefficient of variation differences across the age groups and driving conditions

Three-way repeated measure analyses were conducted, examining separately the COV measures for the rural and urban conditions, with traffic load and distraction as within-subject variables and age group as between-subject variable. The “young” group was the reference group for the age group comparisons.

Table 4 shows the analyses of the COV measures for the rural and urban conditions. In the rural conditions there was no effect of age group for any of the measures. There was a large effect of traffic load for the COV of headway, with larger COVs in the high traffic load condition (Figure 1a), and a small-medium effect of distraction, with larger COVs in the no distraction condition (Figure 1b). There was a large effect of traffic load for the COV of lateral position, with smaller COVs in the high traffic load condition, and a small traffic load by distraction interaction (Figure 2) (all figures are collapsed across the three age groups).

Similarly, in the urban conditions there was no effect of age group for any of the measures. There was a large effect of traffic load for the COV of headway, with larger COVs in the high traffic condition, and a small-medium traffic load by distraction interaction (Figure 3, collapsed across the three age groups).

Table 4

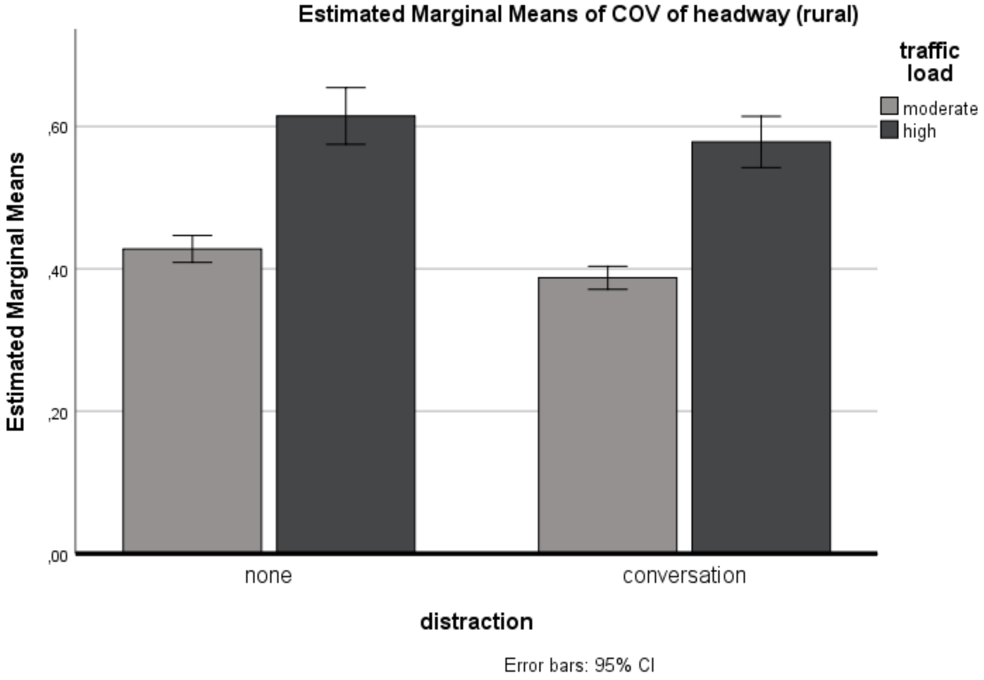
Analyses of COV by traffic load, distraction, and age group in the rural and urban conditions

Variable	Traffic load	Distraction	Age	Traffic load by distraction	Traffic load by age	Distraction by age	Traffic load by distraction by age
RURAL							
Speed COV	F(1,69)=2.16 $p > .05$	F(1,69)=0.01 $p > .05$	F(2,69)=1.11 $p > .05$	F(1,69)=3.30 $p > .05$	F(2,69)=0.77 $p > .05$	F(2,69)=1.92 $p > .05$	F(2,69)=0.42 $p > .05$
Headway COV	F(1,69)=118.27 $p < .001$, $\eta_p^2=.63$ high > moderate	F(1,69)=9.47 $p = .003$, $\eta_p^2=.13$ no > distraction	F(2,69)=1.02 $p > .05$	F(1,69)=0.03 $p > .05$	F(2,69)=1.96 $p > .05$	F(2,69)=1.53 $p > .05$	F(2,69)=2.89 $p = .063$
Lateral position COV	F(1,69)=70.89 $p < .001$, $\eta_p^2=.51$ moderate > high	F(1,69)=0.76 $p > .05$	F(2,69)=0.45 $p > .05$	F(1,69)=4.55 $p = .04$, $\eta_p^2=.06$	F(2,69)=2.97 $p = .058$	F(2,69)=1.21 $p > .05$	F(2,69)=2.50 $p > .05$
URBAN							
Speed COV	F(1,57)=2.88 $p > .05$	F(1,57)=0.85 $p > .05$	F(2,57)=0.20 $p > .05$	F(1,57)=0.13 $p > .05$	F(2,57)=1.34 $p > .05$	F(2,57)=1.27 $p > .05$	F(2,57)=0.04 $p > .05$

Headway COV	F(1,57)=40.79 $p < .001$, $\eta_p^2=.42$ high > moderate	F(1,57)=1.85 $p > .05$	F(2,57)=1.62 $p > .05$	F(1,57)=5.81 $p = .019$, $\eta_p^2=.09$	F(2,57)=1.40 $p > .05$	F(2,57)=0.72 $p > .05$	F(2,57)=1.89 $p > .05$
Lateral position COV	F(1,57)=2.74 $p > .05$	F(1,57)=0.00 $p > .05$	F(2,57)=0.27 $p > .05$	F(1,57)=0.35 $p > .05$	F(2,57)=0.04 $p > .05$	F(2,57)=1.09 $p > .05$	F(2,57)=0.41 $p > .05$

Figures 1 (a & b). COV differences in headway across the age groups in the Rural conditions

a. Emphasis on traffic load differences



b. Emphasis on distraction differences

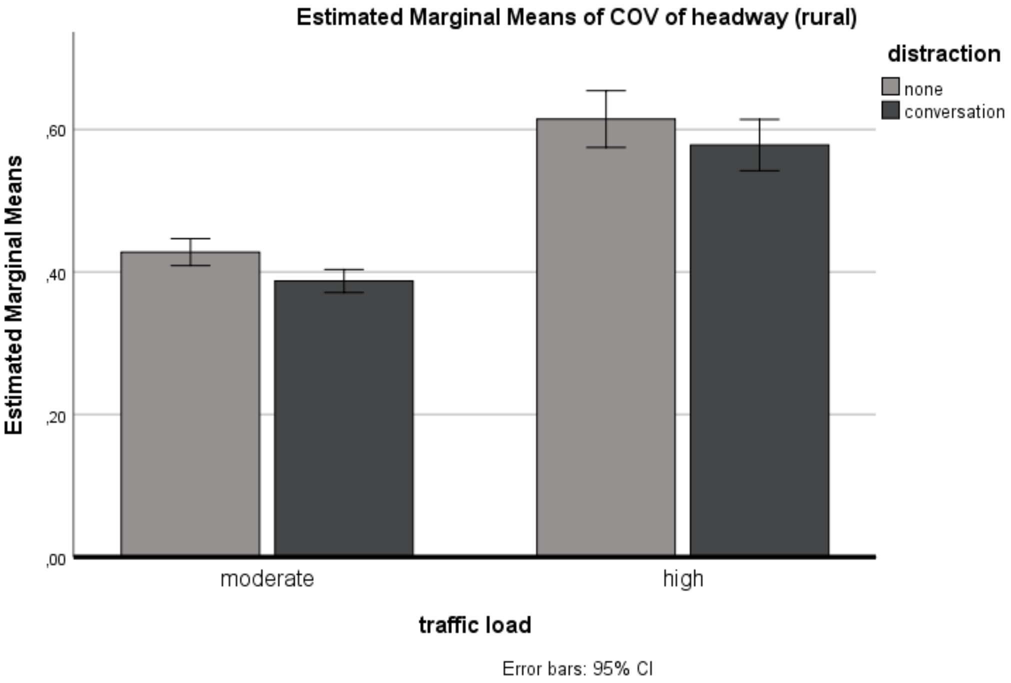


Figure 2. COV differences in lateral position across the age groups in the Rural conditions

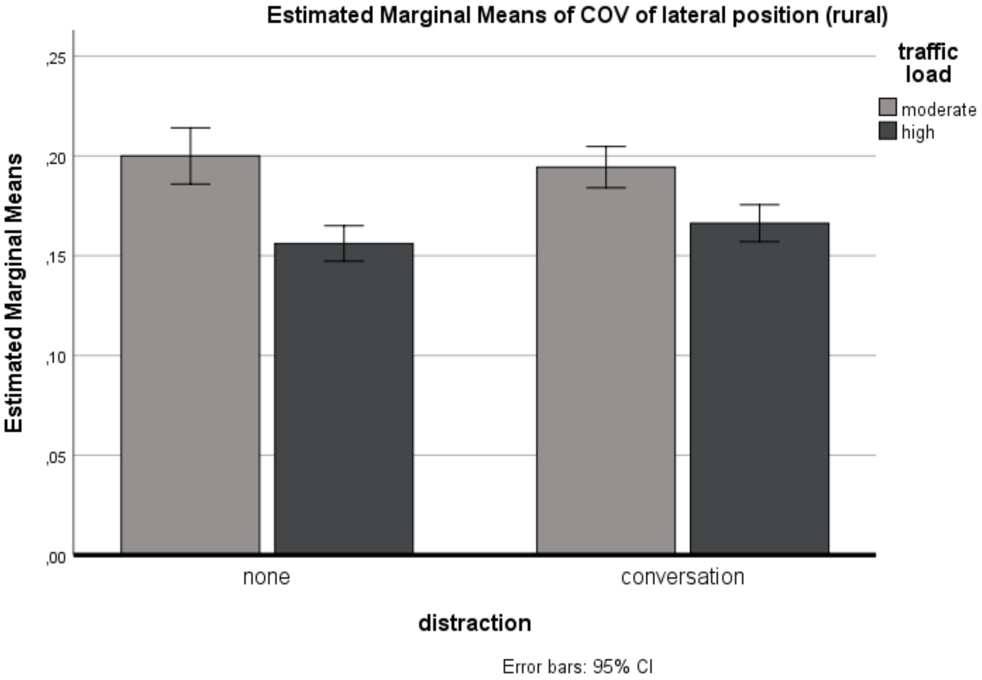
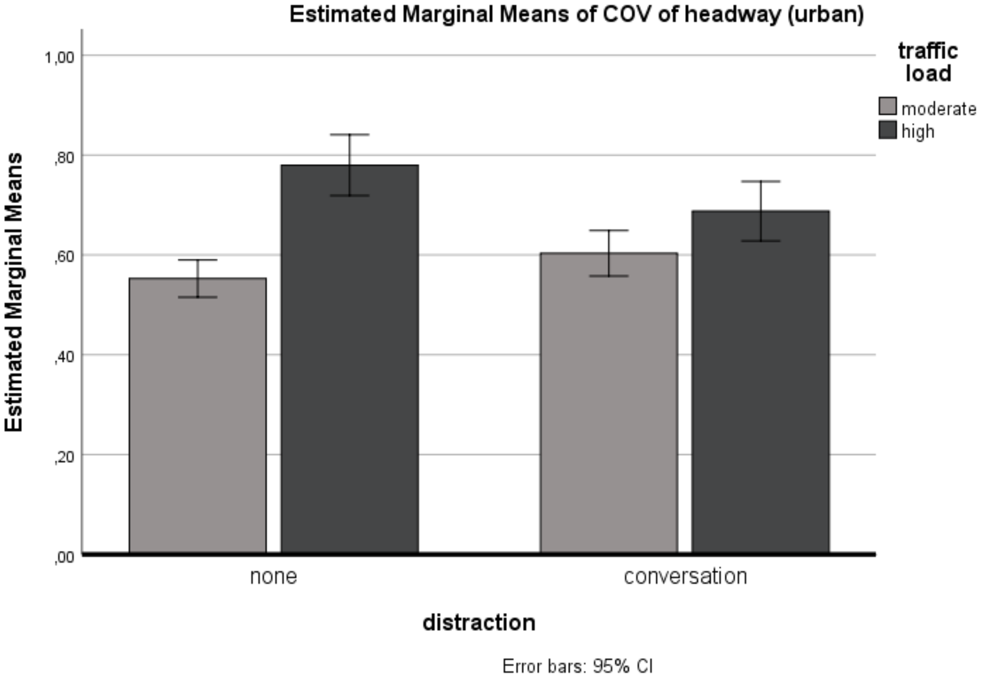


Figure 3. COV differences in headway across the age groups in the Urban conditions



4. Discussion

Significant differences in COV of traffic load were observed in the rural conditions for headway distance and lateral position but not for speed, with large effect sizes (as per Cohen, 1992). Conditions of high traffic resulted in larger COVs of headway distance in all the age groups compared to conditions of moderate traffic but in smaller COVs of lateral position in all the age groups compared to conditions of moderate traffic. Considerably smaller effects of distraction were observed, in the opposite direction from that expected: COVs of headway were larger in the no distraction conditions; similarly, COVs of lateral position showed a traffic load by distraction interaction, with smaller COV in the high relative to the moderate traffic load condition for the no distraction relative to the distraction condition. The findings partly confirmed our second hypothesis of greater intraindividual variability in conditions of greater task complexity, as exemplified by high traffic load, to be discussed further below. No effect of age group was observed in any of the COV analyses, contrary to our first hypothesis that older drivers would show greater intraindividual variability than younger drivers. However, studies of intraindividual variability typically employ newly learned psychomotor tasks, that are susceptible to age effects, whereas the tasks of the present study were well ingrained.

When comparing mean changes in the driving measures themselves as a function of traffic load and age group in the rural conditions, both factors were significant. Conditions of high traffic resulted in lower driving speed and speed variability, smaller headway distance and headway distance variability, larger lateral position and smaller lateral position variability than conditions of moderate traffic. The “old” group drove slower, showed smaller variability consistent with its slower driving speed; left larger headway distances; and showed greater headway distance variability than the “young” group (the reference group).

Distraction effects were only observed in headway variability (*SD*), with greater variability observed in the no distraction condition.

Significant differences in COV were observed in the urban conditions in headway distance only, with a large effect size. Conditions of high traffic resulted in larger COVs of headway in all the age groups compared to the conditions of moderate traffic. Moreover, there was a small-medium traffic load by distraction interaction, with larger COV in the high traffic condition for the no distraction relative to the distraction condition. As in the rural conditions, when comparing mean changes in the driving measures themselves as a function of traffic load and age group, both factors were significant. Conditions of high traffic resulted in lower driving speed, smaller headway distance and headway distance variability than conditions of moderate traffic. Age effects were observed in most driving measures, as in the rural conditions.

The larger headway COVs observed in both rural and urban conditions in conditions of high traffic irrespective of distraction in all three age groups likely reflect the attempts of the drivers to adjust their distance from the lead vehicles. Interestingly, conditions of high traffic resulted in smaller COV of lateral position than conditions of moderate traffic in the rural conditions for in all three age groups, reflecting *improvement* in maintaining position in the road. Lack of corresponding differences in COV of lateral position in the urban conditions may be accounted for by differences in the driving environments between the two conditions. The urban environment was more complex; drivers drove slower on average, which may have affected them more than traffic load when maintaining position in the road.

The findings of the present study with respect to the driving conditions are consistent with the cognitive control hypothesis of Engström, Markkula, Victor, and Merat (2017). According to the proposed hypothesis, driving involves a mix of sub-tasks with variable stimulus-response contingencies. The effect of cognitive load on driving is selective and task-dependent: cognitive load selectively affects those driving sub-tasks that rely on cognitive control, such as non-practiced tasks, but not those for which the driver falls on “default” automatized routines. The stronger the stimulus-response link is in real driving and the greater the practice, the more automatized the sub-task becomes.

According to the above theoretical framework, lateral control (*SD* of lateral position) and longitudinal control (speed) are well-practiced and consistently mapped tasks for the regular driver. Note that headway distance in the case of the present study does not refer to maintaining an instructed headway distance, as in some of the studies reviewed by Engström et al. (2017). Rather, it is more akin to “strong looming”, that is, the optical expansion of the lead vehicle typically observed after the brake light onset or during heavy traffic flow, to signal slowing down. However, no unexpected looming occurred in the present study requiring braking, which would be unaffected by cognitive load according to their framework; rather, high traffic load necessitated the continuous monitoring of headway distance. The smaller COV of headway in the distraction relative to the no distraction condition in both rural and urban environments was unexpected and needs to be replicated. It is difficult to reconcile with the larger COVs of headway in high traffic and indicates that conversation and high traffic do not exert the same effect on cognitive resources.

Moreover, the studies reviewed by Engström and colleagues employed mean speed and headway measures so direct comparisons with the present study are not possible. Although no mean differences as a function of distraction were found in the present study, *SD* of headway decreased in the distraction relative to no distraction conditions in both driving environments.

A different picture emerged for COV of lateral position. Interestingly and perhaps counter-intuitively, in our study conditions of high traffic load *reduced* the COV of lateral position indicating improved lane-keeping performance. This observation is consistent with the hypothesis of Engström et al. (2017) and with the studies reviewed by the investigators, according to which improvement of an automatic skill under cognitive load occurs due to a global enhancement in neural responsiveness associated with the deployment of cognitive control. Lane-keeping performance can be considered an automatic sub-task. Studies that employ RT tasks, on the other hand, are more akin to the driving studies reviewed by the investigators that employ tasks that are unnatural and non-practiced in everyday driving. Such tasks are susceptible to interference from cognitive load or to the reduced executive functioning associated with aging. As lane-keeping and headway control occur concurrently, performance on the driving subtask that relies on cognitive control will be impaired whereas performance on the subtask that is automatized will improve.

4.1. Limitations

A limitation of the present study is the sample size of the “old” group, especially in the urban conditions, which may have reduced the power of the study. Attrition is common in driving simulation studies and can introduce bias in the results. It was calculated at 13% of participants of different ages from four studies (Brooks et al., 2010) and is more frequent in older than in younger drivers (Brooks et al., 2010; Keshavarz, Ramkhalawansingh, Haycock, Shahab, & Campos, 2018; Matas Nettelbeck, & Burns, 2015), with a dropout rate of 29% in one study (Matas et al., 2015). Driving environment can also influence attrition, with urban environments being associated with more frequent incidents of simulator sickness (Mourant, Rengarajan, Cox, Lin, & Jaeger, 2007). Our dropout rate for the “middle-aged” group was 4%-10% in the rural and 8-15% in the urban conditions, whereas for the “old” group it was 19%-41% in the rural and 25%-40% in the urban conditions. The rates are consistent with those of other studies and show that simulator sickness is more prevalent in older adults and in urban environments.

Another limitation is that the “old” group was not particularly old, which limits the generalizability of the results to drivers over 80 years of age that still drive.

5. Conclusions

Rural conditions of high traffic load resulted in increased COV of headway distance and decreased COV of lateral position as compared with conditions of moderate traffic load. Urban conditions of high traffic load resulted in increased COV of headway distance only as compared with conditions of moderate traffic load. The results indicate that the effects of traffic load on driving are selective and task-dependent and may relate to the degree of automatization of the task. Skills that are highly automatized result in enhancement under conditions of traffic load, whereas less automatized skills show increased variability. Age was not associated with any increases in COV in the age ranges studied. The findings underscore the importance of adjusting for mean performance when examining variability measures and point to the differential effect of traffic conditions on intraindividual variability measures.

CRediT authorship contribution statement

Alexandra Economou: Conceptualization, Methodology, Formal analysis, Data curation, Writing - Original Draft, Writing - Review & Editing, Visualization. **Ion Beratis:** Conceptualization, Formal analysis, Investigation, Data curation, Writing - Review & Editing. **Eleonora Papadimitriou:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing - Review & Editing. **George Yannis:** Conceptualization, Methodology, Software, Writing - Review & Editing, Supervision, Project administration, Funding acquisition. **Sokratis G. Papageorgiou:** Conceptualization, Methodology, Resources, Writing - Review & Editing, Project administration.

Declarations of Competing Interest: None

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