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Intraindividual variability in driving simulator parameters of healthy drivers of different ages

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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 and to adaptive changes to traffic condition challenges.

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 sim-

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ilar for all persons (Hultsch et al., 2002; Hultsch, et al., 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. Applying the above definitions to driving performance, diversity would pertain to differences between persons of a given group, such as older persons; dispersion would pertain to variability of single persons on multiple conditions of a single driving task; and inconsistency would refer to the variability of single persons on a single task presented 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 et al., 2014; Christensen et al., 1999; Deary & Der, 2005; Dixon et al., 2007; Hultsch et al., 2005; Hultsch et al., 2002; Hultsch & MacDonald, 2004; Vasquez et al., 2016; review by Haynes et al., 2017a). Inconsistency correlated negatively with cognitive measures (Hultsch et al., 2002) and errors (Haynes et al., 2017b), was associated with executive functioning performance (Vasquez et al., 2016), and predicted cognitive decline and mortality in older adults (Batterham et al., 2014; Haynes et al., 2017a; Lövdén et al., 2007; Yao et al., 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 et al., 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 et al., 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 et al., 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 than mean performance 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 years and older and especially 60 years 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 et al., 2009; Fofanova & Vollrath, 2011; Irwin et al., 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 et al., 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 et al., 2012; Cantin et al., 2009; Choudhary & Velaga, 2018; Cuenen et al., 2016; Hornberry et al., 2006; Irwin et al., 2015; Onate-Vega et al., 2020; Rumschlag et al., 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); high complexity road environments, with roads with curves resulting in lower speed and higher *SD* of speed and lateral position than straight roads (Onate-Vega et al., 2020); 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, *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 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% and 96% completed all four rural and between 85% and 92% all four urban driving conditions. Of the "old" participants between 59% and 81% completed all four rural and between 60 and 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 × 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. To validate the driving simulator against a real environment, a study was conducted with a group of 31 drivers between 20 and 30 years of age. The drivers drove both on the simulator and a real car in an interurban road. The driving simulator scenario was programmed to simulate with high precision the interurban road task and lognormal regression models were developed for the identification of the effect of driving environment (simulated-real), driver characteristics and driving performance variables (average acceleration, deceleration, and their *SDs*) on average vehicle speed change. Relative validity for

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)

Note. 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.

the simulator was established: fast and slow drivers showed the same speed difference and drivers conversing with a passenger or not conversing also showed the same speed difference (Yannis et al., 2015).

The study design and procedure have been explained elsewhere (Yannis et al., 2013). Participants were briefed prior to the beginning of the experiment on the full procedure to follow, emphasizing the importance of maintaining their usual driving behavior. First, they underwent a 5–10-minute practice drive in which they practiced handling the simulator, keeping the lateral position of the vehicle, keeping a stable speed that is appropriate for the driving environment, and stopping at intersections and braking. The instructions were the same for the driving scenarios, that is, to try and stay within the speed limits and within the lanes. There were no restrictions about driving behavior, e.g., overtaking. After the 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 min each, with each session corresponding to a different driving environment; a break was introduced between the two sessions to reduce simulator sickness. Each driving scenario in the rural environment was 2.1 km long and lasted 3.5 min. After the end of each trial the screen turned black for a few seconds and restarted at the beginning of the next trial. The total length of the drive was 12.6 km and lasted 20 min. Each driving scenario in the urban environment was 1.7 km long and lasted 3.5 min. Similarly, at the end of each trial the screen turned black for a few seconds and restarted at the beginning of the next trial. The total length of the drive was 10.2 km and lasted 20 min. 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. The behavior of ambient traffic was covered by the default traffic behavior features of the simulator, as the focus of the simulation was on the global traffic conditions experienced by the participant during the simulated drive rather than simulating in detail the behavior of a few selected vehicles. 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. The use of the same research associate and a selected list of topics was implemented in order to ensure consistency of conversation across drivers.

In the rural driving environment participants drove on a single carriageway rural route of 3 m lane width with zero gradient and mild horizontal curves. In the urban driving environment participants drove on an 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 the 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, which we surmised was to avoid a task that might challenge their driving performance. 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 et al., 2017b).

3. Results

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

In the context of the GLM, 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. Due to the fixed nature of our experimental manipulations we considered the simpler GLM analyses as appropriate for our data. Participant attrition was higher in the older group due to simulator sickness; however, no differences in COV were observed between older participants who did not complete all the driving scenarios and those who did (see below and Appendix A).

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 effect 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

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 η_p^2 = 0.49 moderate > high	F(1,69) = 0.53 p > .05	F(2,69) = 7.69 p = .001, η_p^2 = 0.18 old < young	F(1,69) = 2.00 p > .05	F(2,69) = 4.70 p = .012, η_p^2 = 0.12	F(2,69) = 1.64 p > .05	F(2,69) = 6.33 p = .003, η_p^2 = 0.16
Headway	F(1,69) = 685.60 p < .001, η_p^2 = 0.91 moderate > high	F(1,69) = 0.02 p > .05	F(2,69) = 7.17 p = .001, η_p^2 = 0.17 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, η_p^2 = 0.71 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, η_p^2 = 0.29 moderate > high	F(1,69) = 0.24 p > .05	F(2,69) = 4.36 p = .017, η_p^2 = 0.11 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, η_p^2 = 0.81 moderate > high	F(1,69) = 5.88 p = .018, η_p^2 = 0.08 no distraction > conversation	F(2,69) = 8.08 p = .001, η_p^2 = 0.19 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, η_p^2 = 0.36 moderate > high	F(1,69) = 0.43 p > .05	F(2,69) = 2.34 p > .05	F(1,69) = 5.86 p = .018, η_p^2 = 0.08	F(2,69) = 2.85 p > .05	F(2,69) = 0.95 p > .05	F(2,69) = 2.83 p > .05

Note. Age reference category: young group.

to medium traffic load by distraction interaction effect 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.

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 effect 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 interaction effects 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 effect for headway showed a differentiation of the effect of distraction as a function of traffic load in the different age groups.

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 (Fig. 1a), and a small-medium effect of distraction, with larger COVs in the no distraction condition (Fig. 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 effect (Fig. 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 effect (Fig. 3, collapsed across the three 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 $p < .001$ $\eta_p^2 = 0.47$ moderate > high	F(1,57) = 0.41 $p > .05$	F(2,57) = 11.49 $p < .001$, $\eta_p^2 = 0.29$ middle-aged < young, old < young	F(1,57) = 3.24 $p > .05$	F(2,57) = 3.60 $p = .034$, $\eta_p^2 = 0.11$	F(2,57) = 0.09 $p > .05$	F(2,57) = 0.75 $p > .05$
Headway	F(1,57) = 188.29 $p < .001$, $\eta_p^2 = 0.77$ moderate > high	F(1,57) = 2.24 $p > .05$	F(2,57) = 3.63 $p = .033$, $\eta_p^2 = 0.11$ old > young	F(1,57) = 0.00 $p > .05$	F(2,57) = 3.26 $p = .046$, $\eta_p^2 = 0.10$	F(2,57) = 1.65 $p > .05$	F(2,57) = 4.31 $p = .018$, $\eta_p^2 = 0.13$
Lateral position	F(1,57) = 1.68 $p > .05$	F(1,57) = 0.78 $p > .05$	F(2,57) = 4.00 $p = .024$, $\eta_p^2 = 0.12$ 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 $p = .011$, $\eta_p^2 = 0.15$ 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 $p < .001$, $\eta_p^2 = 0.54$ moderate > high	F(1,57) = 5.44 $p = .023$, $\eta_p^2 = 0.09$ no distraction > conversation	F(2,57) = 2.43 $p > .05$	F(1,57) = 5.35 $p = .024$, $\eta_p^2 = 0.09$	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 $p > .05$

Note. Age reference category: young group.

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 $p < .001$, $\eta_p^2 = 0.63$ high > moderate	F(1,69) = 9.47 $p = .003$, $\eta_p^2 = 0.13$ 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 $p < .001$, $\eta_p^2 = 0.51$ moderate > high	F(1,69) = 0.76 $p > .05$	F(2,69) = 0.45 $p > .05$	F(1,69) = 4.55 $p = .04$, $\eta_p^2 = 0.06$	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 $p < .001$, $\eta_p^2 = 0.42$ high > moderate	F(1,57) = 1.85 $p > .05$	F(2,57) = 1.62 $p > .05$	F(1,57) = 5.81 $p = .019$, $\eta_p^2 = 0.09$	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 $p > .05$

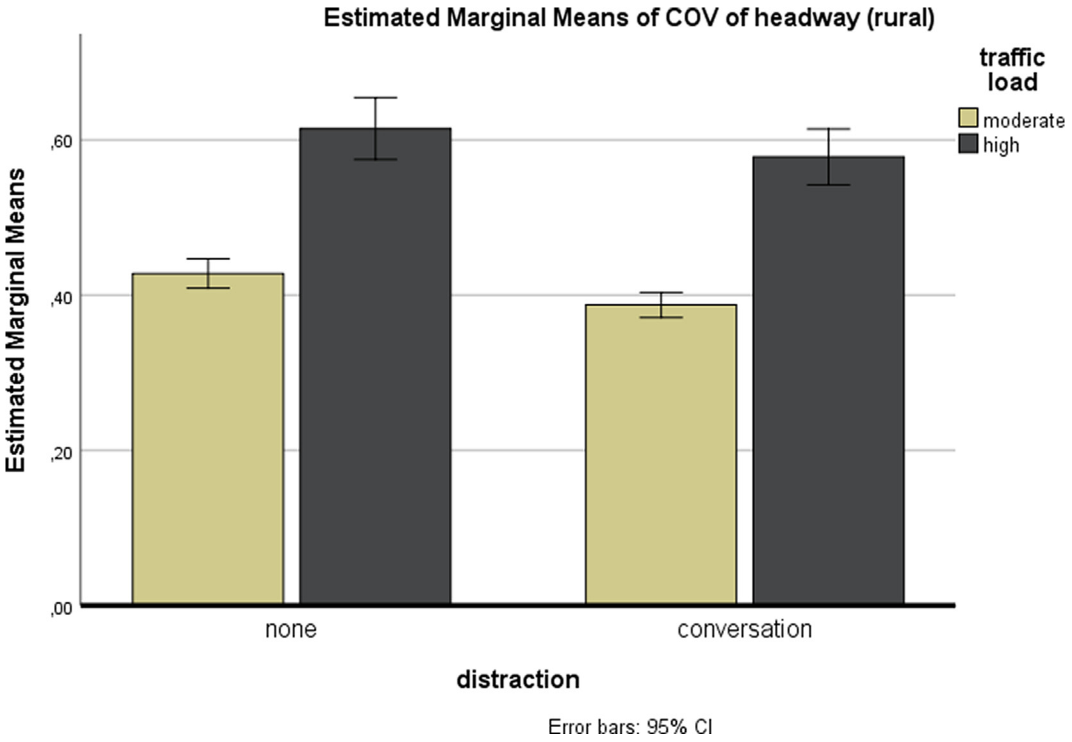

Fig. 1. COV differences in headway across the age groups in the Rural conditions.

Due to participant attrition affecting primarily the “old” group, we compared the COVs of speed, headway, and lateral position in the rural and urban conditions between drivers who were included in the analyses and those who were not because they missed one or more of the driving conditions. None of the 12 comparisons were significant for the rural conditions and one out of the 12 comparisons was significant for the urban conditions (Appendix A). With the caveat that the number of excluded participants was small in some of the comparisons, the F values were overall very low, indicating no significant differences in the measures.

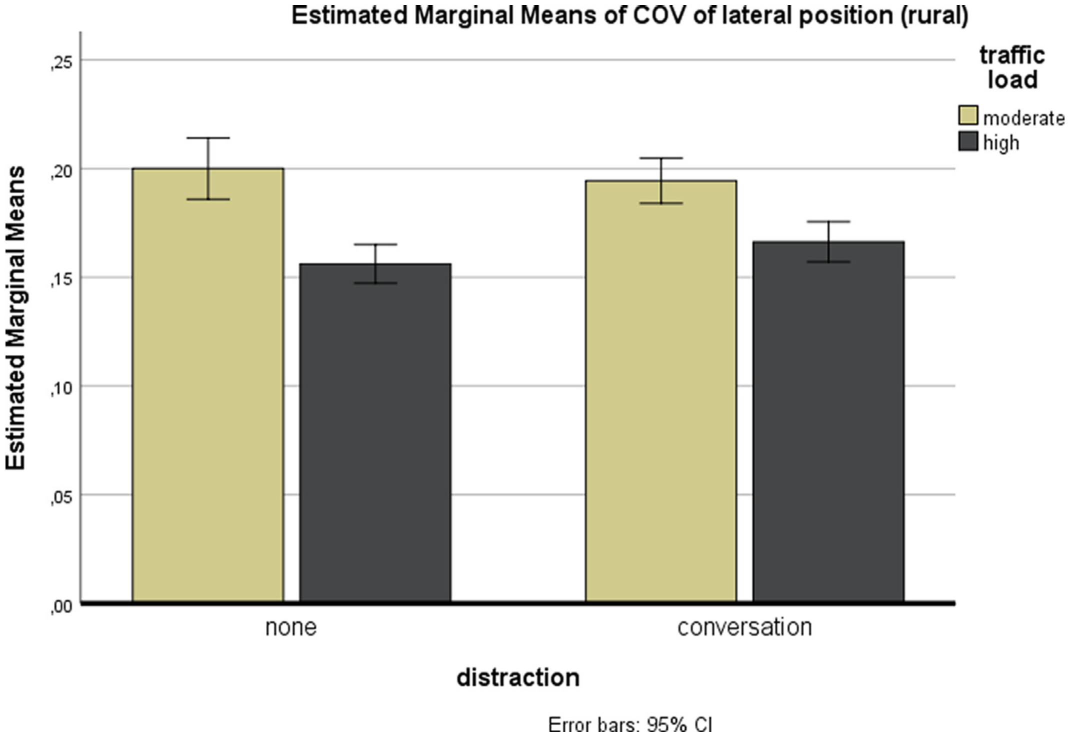

Fig. 2. COV differences in lateral position across the age groups in the Rural conditions.

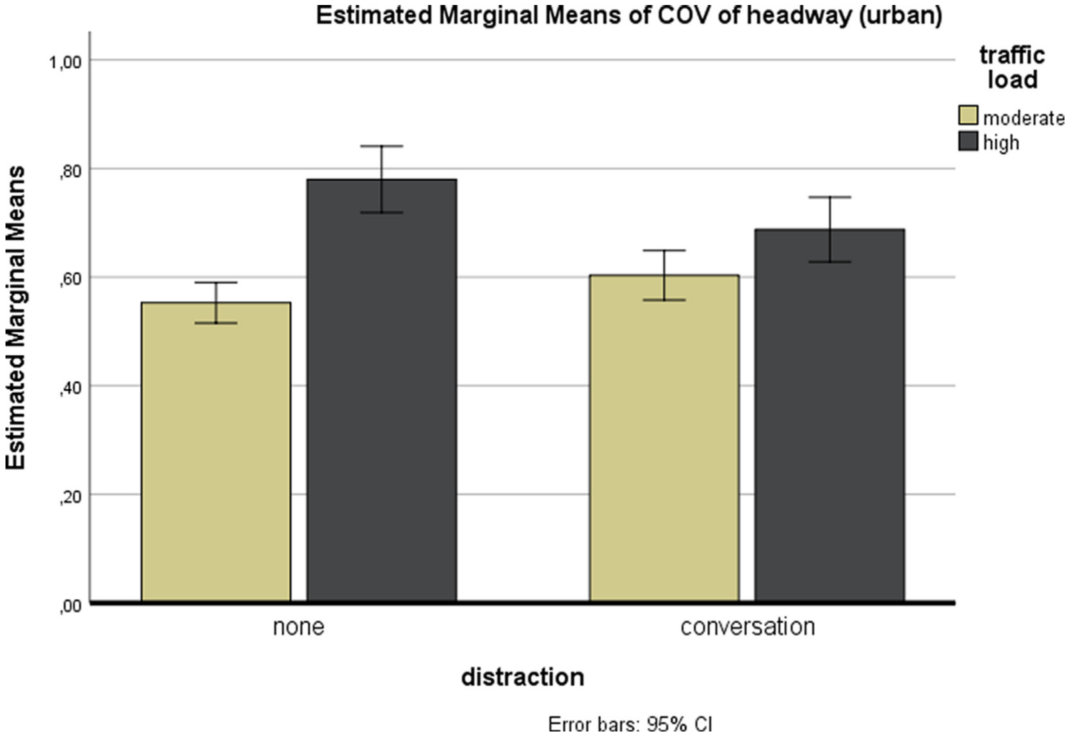

Fig. 3. COV differences in headway across the age groups in the Urban conditions.

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. Not all RT tasks demonstrate age effects, however. A study employing the RT COV in a sustained attention RT task in participants spanning from the second to the seventh plus decade of age showed no age effects (Carriere et al., 2010), which indicates according to the authors no decline in task disengagement with age.

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.

The smaller effect of distraction relative to traffic load in COV, albeit in the opposite direction, is consistent with Onate-Vega et al. (2020), who showed that the road environment had a stronger effect on driving performance than secondary task demands, and cognitive distraction did not have an effect on mean speed, *SD* of speed and *SD* of lateral position in a group of young drivers in rural environments. In our study, cognitive distraction did not have an effect on mean speed, *SD* of speed and *SD* of lateral position in either environment.

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 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, which limit any direct comparisons between them. 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 regarding lateral position raise the question of their transfer to real-world driving. Validity, relative or absolute, for lateral position measures was demonstrated in only 4/13 studies (review by Wynne et al., 2019). Of the studies reporting non-valid results, however, most found more variation in simulated compared to real driving, indicating that the reduction in our measure is not an artifact of simulated driving.

The findings of the present study with respect to the driving conditions are consistent with the cognitive control hypothesis of Engström et al. (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 subtask. 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. Headway variability, on the other hand, may have an adaptive nature indicating responsiveness to the traffic demands. Howcroft et al. (2019) found greater deceleration variability in speed in naturalistic in-car driving in older persons with better cognitive health compared with those with worse cognitive health using the COV of speed. The researchers interpreted the increase in variability as a cognitive adaptation to environmental factors as needed. Direct comparisons between the two studies are not possible due to the naturalistic drives usually taking place in known or familiar routes, the location of which (urban-non-urban) can only be indirectly inferred. Nevertheless, that deceleration event variability distinguished between older drivers with different cognitive health suggests that the COV is a measure that merits further consideration. Larger COVs of headway in conditions of high traffic may therefore indicate better self-regulation in the more challenging traffic conditions. It would be interesting to examine COV differences in drivers differing in cognitive health from our greater sample of participants in a future study.

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 et al., 2018; Matas et al., 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 et al., 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. A comparison of the drivers who were included with those who were not, however, did not reveal any differences in COV between the two groups. Using a linear mixed model in future analyses would address the problem of bias and reduced power due to missing data.

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. COV measures merit further consideration in driving research as they reflect variability that is not accounted for by differences in mean performance that may indicate adaptative changes to traffic condition challenges.

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.

Declaration of Competing Interest

The authors declare that they have no known competing financial or other interests that could have influenced the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2021.02.002.

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