Original Article

The Effect of Age on Driving Performance in Iran Using Driving Simulator

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Abstract

Background and Objectives: Nearly 16,000 people are killed in driving accidents in Iran each year. The purpose of this study was, therefore, to determine the effect of age on driving performance, using a driving simulator. **Methods:** This cross-sectional study was carried out on 16 young drivers, 16 middle-aged drivers, and 16 elderly drivers in Tehran. Driving simulators were used to check the drivers' performances. The main scenario was driving on a freeway at an average speed of 50 km/h, when pedestrians suddenly appeared at a distance of 40 m and the drivers had to brake immediately after noticing the pedestrian. The time interval between the emergence of the pedestrian and stepping on the brake pedal was continuously recorded as the reaction time and the amount of vehicle deviation from the center of the road as the lateral deviation of the vehicle. The drivers' mental workload was recorded after the simulated driving test, using the verbal online subjective opinion scale. **Results:** The elderly drivers had the highest mean reaction time, 963.8 ms, and there was no significant difference between the mean reaction time for youth and middle-aged drivers (858.3 ms vs. 860 ms). Elderly drivers showed high lateral deviation, 0.69 m, and mental workload, 6.19, whereas youth drivers had the lowest lateral deviation (0.55 m) and mental workload (3.60). MANOVA revealed a significant effect of age (Pillai's trace, $V = 0.55$, $P < 0.001$). Univariate ANOVA showed that age significantly affected the lateral deviation ($P < 0.001$) and mental workload ($P < 0.001$), but reaction time wa not age dependent ($P = 0.101$). Poisson regression revealed no significant effect for age on the number of collisions ($P = 0.357$). **Conclusion:** Based on the variables under study, driving performance of the elderly group was poor as compared to that of the middle-aged and young ones. Old drivers were subjected to greater mental workload when responding to the stimulus of the driving environment.

Keywords: Age, lateral deviation, modified cooper-harper scale, reaction time, verbal online subjective opinion scale

Introduction

According to present reports, road traffic accidents are responsible for the deaths of 1.2 million people every year, and in total, they cause a disability of 20–50 million people in the world.[1] Iran is one of the countries with the highest rates of road accidents in the world. According to the annual statistics by the Iranian Legal Medicine Organization, 15,932 people have lost their lives in road traffic accidents in 2016. According to the figures in this report, over 75% of road deaths occur among men. About 25.7% of these casualties are aged 18–29, 30.4% are 30–49 years old and 30.3% are aged 50 and older. Although the number of road accident victims in 2016. It has decreased

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by 3.9% compared to the previous year; it still shows a quite high rate.[2] The cost of road traffic accidents, especially in low- and medium-income countries, including Iran, is estimated to range from 1% to 2% of the gross national product.[3] Some studies consider road traffic accidents an indicator of the quality of life in many countries.[4] Road traffic accidents may have different causes. According to studies conducted in this field, human error is the most important cause of these types of accidents in 57% of cases.[5] Rovšek *et al*., for instance, argued that traffic accidents and related injuries in Slovenia occurred due to a combination of different factors, most notably human errors (driving on the wrong lane, for example).[6] Sugiyanto also considered human errors as the most important cause of accidents.[7] The mental workload can be regarded as another driving-related performance factor. Since the early 1990s, the hard work of operators, especially, that of pilots and air traffic controllers, has led to a shift of attention to mental workload.[8] Many studies have shown that jobs with heavy workloads lead to reduced efficiency, reduced learning and memory, impaired thinking, irritability, and excitability due to fatigue and inappropriate schedules.[9] The workload is used to define the effects of tasks which require information processing and energy consumption. More specifically, the mental workload is the amount of information processing capacity that is used to perform a task. Workload depends on the individual and the interaction between the operator and the task structure, and the same requirements of the tasks do not lead to the same levels of workload for all individuals.[8] It should be noted that many driving accidents occur due to disturbing mental workload, or at least are associated with it. This is when the mental workload is either very low or very high.[10] Various behavioral, self-reporting, and physiological methods have been successfully used so far to measure the mental workload.[11]

One of the best ways to measure the mental workload is the evaluation of the individuals' reaction time.[8] Reaction time is the time interval between the emergence of a stimulus and the individual's response. Many studies carried out around the world have used brake time as an important criterion to measure the drivers' reaction time and to test their performances.[12] Brake reaction time consists of the perception of time and the movement time. Some studies have examined both the driver's perception and movement time.[13-15] These studies can provide more precise analysis; because, they have the opportunity of the accurate examination of motor and cognitive abilities of the drivers. Many studies have only evaluated the overall brake reaction time,[15-18] depending on their facilities and purpose. Experts consider the lateral deviation of the vehicle as one of the most important indicators of the impaired driving performance, which can be interpreted as the probability of leaving the centerline and being engaged in a crash. If the driver is not in good condition for any reason, such as fatigue or taking drugs, the number of lateral deviations increases.[19] Now, we have to figure out what factors can affect the drivers' workload. Briefly, De Waard *et al*. divides the factors affecting the driver workload into three categories: 1 – Factors that influence the driver's status such as monotony of road environment, fatigue, painkillers and alcohol, 2 – Factors that influence the driver's behavior such as driver's experience, age and strategy, 3 – Environmental factors such as road environmental requirements, traffic, vehicle ergonomics and automation.[8]

Based on the studies by De waard, driver's age is one of the factors that influence the driving behavior. It has been reported that elderly drivers may have difficulty adapting their driving behaviors to complex traffic situations. For example, an article on crash situations has reported that elderly drivers have shown more accidents than young drivers.[20] Other similar data also confirm the findings.[21-23] The reason is not quite clear.[24]

There is little information available on the effects of age on driving performance in Iran. This is especially true for the studies using a driving simulator. Simulators are machines that simulate the driving environment and vehicle conditions and are used for training,[25-27] evaluation,[28] and research[29-33] purposes. An example of studies with a focus on the effect of age, using a driving simulator is the study by Verwey in this experiment, young and old drivers performed a visual recognition task or an extra simple task while driving on the road. According to their findings, the old drivers had poorer performance than the young ones when driving on the highway and at intersections.[34] The present study seeks to test the driving performance of the three age groups: young, middle-aged, and old drivers. The aim of this study is, therefore, to determine the effect of age on Iranian drivers' performances by paying attention to the mental workload and using a driving simulator.

Methods

Subjects

This cross-sectional study was conducted on 16 young drivers (20–29 years old), 16 middle-aged drivers (41–53 years old), and 16 elderly drivers (57 years old) in Tehran in 2017. We consider 57 years because of the conditions in Iran and because the number of volunteer drivers with the age of >60 years old were not so many. All drivers were male. Subjects were found by posting notices in 22 districts of Tehran. Drivers who had the tendency to participate in the study were volunteers that had inclusion criteria. We tried to use drivers of all areas of Tehran city to minimize the related biases. The inclusion criteria were: being male, filling informed consent, having enough sleep of 8 h the night before the test, having a driving license for at least 2 years, driving at least once in a week, having the adequate or corrected vision of $\frac{9}{10}$ or $\frac{10}{10}$ per eye, not having taken psychedelic, sedative, or hypnotic drugs. The exclusion criteria were: deciding to leave the study, showing symptoms of discomfort caused by the simulator, expressing physical discomfort, for any reason, after starting the test.

Measurement instruments

Driving simulator

The driving simulator used in this study is a half-body Pride

Model 131 (Saba) made by the specialists of the virtual reality group of Khajeh Nasir Tusi Industrial University. The simulator has a computer and graphics card (Core i7 Intel processor and Graphics card NVIDIA GeForce GTA 4 GB) and software tools for simulating intra-city and inter-city roads, freeways, night driving, and driving in snowy, rainy, and foggy conditions. Software and programming methods that used were developed by experts at the Department of Virtual Reality of the Khajeh Nasir Toosi University of Technology, using Softwares such as Autocad, C ++, MATLAB, etc. It has also three 29-inch displays and data logging software, real-life steering wheel, and its drive and actuator. Besides, it is equipped with real-life pedals, gear, bonnet, fender, bumper, lights, wheels, steering, indicator, tachometer and speedometer panel, and electronic boards. The acceleration and brake performance simulations match highly with the actual Pride, and it has the same engine sound as the actual vehicle when starting, accelerating, and changing gears. Simulator software provides the ability to calculate parameters such as the reaction time, the vehicle lateral deviation and speed, the degree of steering-wheel rotation, vehicle's longitudinal and lateral position, and road position [Figure 1].

Self-report scale for mental workload measurement

In this study, the verbal online subjective opinion (VOSO) and the modified cooper-harper scales were used to measure self-reported mental workload.

The VOSO is a simple scale for measuring the mental workload. It is a uni-dimensional self-report scale that shows the amount of individual's mental workload on a horizontal line with a grading of 0–10. Based on the previous studies, this scale shows great sensitivity to short periods of mental workload.[35,36] The minimum and maximum scores of this scale were 0 and 10, respectively. Scoring begins with asking participants to show their perception of mental workload on this scale. Higher score means higher level of mental workload and lower score means lower level of mental workload. The validity and reliability of the VOSO scale have been examined and confirmed by Charkhandaz Yeganeh *et al*. in Iran.[37]

Research process

Participants were fully informed of the test conditions and completed the consent form. They were provided with some explanations on how the study would be conducted. Then, the below steps were performed.

Figure 1: Driving simulator used in the study

First, the demographic information and the simulator discomfort questionnaires were completed and the visual acuity of the subject was checked. Visual acuity of participants was assessed using the Snellen test before performing the test. The questionnaires included questions on age, the amount of sleep the night before the test, driving experience, driving simulator experiment, history of using psychedelic and sedative drugs within the last 24 h, presence or absence of headache, dizziness, nausea, feeling of feebleness or sickness, shortness of breath, cardiovascular, and motor diseases.

Drivers then drove about 10 min on a path different from that of the main phase of the test to get familiar with the simulator and how it works. After that, they had a 5-min interval to rest before the main test phase started. Finally, the participants had to drive on the road of the main scenario of the study.

The road on which the drivers were to drive was the simulated path of a freeway. Individuals were to drive at an average speed of 50 km/h and were not supposed to leave their lane. Drivers were also asked to hold the steering with two hands. Obstacles in the form of pedestrians appeared suddenly along the road at a specific distance (40 m). Participants should brake as quickly as possible to avoid a collision with the pedestrians or running them down. Obstacles emerged abruptly at intervals of 300–900 m. The time interval between the appearance of the obstacle (pedestrian) and stepping on the pedal was recorded as a driver reaction time by the simulator software. After braking, the driver should accelerate to about 50 km/h (between 45 and 55 km/h). During the driving, the deviation of the vehicle from the center of the road was continuously recorded as another variable of driving performance by the simulator software. In addition, the drivers were explained that they were not allowed to leave their lane to prevent collision with the obstacles and that any deviation from the lane would be recorded as a lateral deviation and impaired performance. In the next stage, the individual was asked to express the amount of mental workload corresponding to the driving task performed, on the basis of the VOSO scale. The individual was asked to show the amount of mental workload on a scale of 0–10. The collected data were analyzed using the R statistical software (R Core team (2019). R: A language and environment for statistical computing. R foundation for satatistical computing, Vienna, Austria), descriptive and analytical statistics. Participants in the study were accompanied by a questionnaire of informed consent to participate in the study, and researchers had provided them the necessary explanations about the study procedure. Participants could drop out of the study at any stage if they were intended. In the case that they show any complications from the simulator syndrome, their participation in the study were be stopped.

Statistical analysis

Results are given in mean ± standard deviation (SD) or percentage for categorical variables. For each participant, the reaction time, lateral deviation, and VOSO were measured at the same time, multivariate regression (MANOVA) was used to model the correlation between these dependent variables. If the MANOVA result was significant, the univariate linear regression was employed to find which dependent variable was age dependent. Moreover, Poisson regression was used to assess whether the number of collisions are subject to change with aging of participants.

Results

Table 1 shows the mean, standard deviation, and range of the age as well as the performance of participants over the time trials. The mean age of all participants was 36.53 (SD = 15.11) years (with 24.2 ± 2.27 for youth, 43.7 ± 1.39 for middle-aged, and 60.2 ± 2.07 years for elderly subjects). The reaction time was 882.2 ms (SD = 173.2) on average for all participants. Elderly people had the highest reaction time, 963.8 ms, and the mean reaction times for youth and middle-aged participants were similar (858.3 ms vs. 860 ms). A similar observation can be made about lateral deviation and VOSO scale; elderly participants showed high lateral deviation, 0.69 m, and mental workload, 6.19, whereas youth participants had lowest lateral deviation (0.55 m) and mental workload (3.60).

Figure 2 shows the scatter plot of reaction time (panel A), lateral deviation (panel B), and VOSO score (panel C) of individuals against the age. For each study group, the line represents the least squared regression line. Some points are noticeable about Figure 2; the trend in the reaction time and lateral deviation is quite similar among participants so that by increasing the age, the reaction time and lateral deviation decreased among youth and middle-aged groups, but they increased with age among elderly people. Elderly drivers showed an increasing trend (regression line slope was positive) on all variables so that as they got aging, their reaction time, vehicle lateral deviation, and also their workload scores increased. Another point to note is that as age increased, the mental workload was increased at all age groups, although the increase was more sharpened with elderly drivers.

[Moreover, the MANOVA test revealed that there was a significant effect of age on reaction time, vehicle lateral deviation, and VOSO score of participants (Pillai's trace, $V = 0.55$, $P < 0.001$) in total. Since MANOVA is an omnibus test, it only shows that the effect of age was significant without providing details about it was significant on which variable. A univariate ANOVA, therefore, was used to test the effect of age on the reaction time, vehicle lateral deviation, workload scores [Table 2]. Results revealed that age affected the lateral deviation and mental workload, but it had no significant effect on reaction time.

Figure 2 also plots the number of collisions for three age groups. Middle-aged drivers had the lowest number of collisions (0.312 per capita) with no event for most of them (75% of them had no collision) or only one collision (25%). Elderly drivers exhibited the highest number of collisions per person (mean = 0.625) with 62.5% no collision, 18.7% one collision, 12.5% two collisions, and 6.2% three collisions. Poisson regression was employed to test whether the numbers of collisions were affected by the age-groups. Poisson regression revealed no significant effect for age groups on the number of collisions.

Finally, the correlation between the variables of the study can be observed in Table 3.

Discussion

The present study, like that of Makishita and Matsunaga, examined three age groups.[38] The main objective of this study was the survey of age effect on mental workload-related variables in driving. The results of the present study showed that reaction time, lateral deviation of vehicle, and VOSO score were higher in the elderly group. These findings suggest that driving has imposed more amount of mental workload on elderly drivers, and this group had a poorer performance. As referred to in the results part, the scatter plot of variables demonstrates that with increasing age in elderly group, amount of all three main variables, reaction time, lateral deviation and VOSO, were increased. Moreover, the MANOVA test revealed that age had a significant effect on reaction time, lateral deviation, and VOSO; although this effect on the basis of the univariate ANOVA test was significant only for lateral deviation and VOSO. Now we discuss each variable results.

The higher lateral deviation can be associated with a greater perceived mental workload and inadequate performance.

Table 1: The summary descriptive statistics for the study variables

	Overall	Youth	Middle-age	Elderly	Range
Age	36.53±15.11	24.2±2.27	43.7±1.39	60.2±2.07	20-65
Reaction time	882.2±173.2	858.3±195.3	860±124.6	963.8±134.7	556-1403
Lateral deviation	0.59±0.10	0.555±0.095	0.586±0.069	0.691±0.060	0.41-0.85
VOSO	4.25±1.63	3.60±1.32	3.94±1.18	6.19±1.22	1-8
Collision (*n*)					
0	49 (68)	28 (70)	11 (68.7)	10 (62.5)	0-3
1	16 (22)	8 (20)	5 (31.3)	3 (18.7)	
2	5 (7)	3 (7.5)	0 (0)	2 (12.5)	
3	2 (3)	1 (2.5)	0 (0)	1 (6.2)	

VOSO: Verbal online subjective opinion

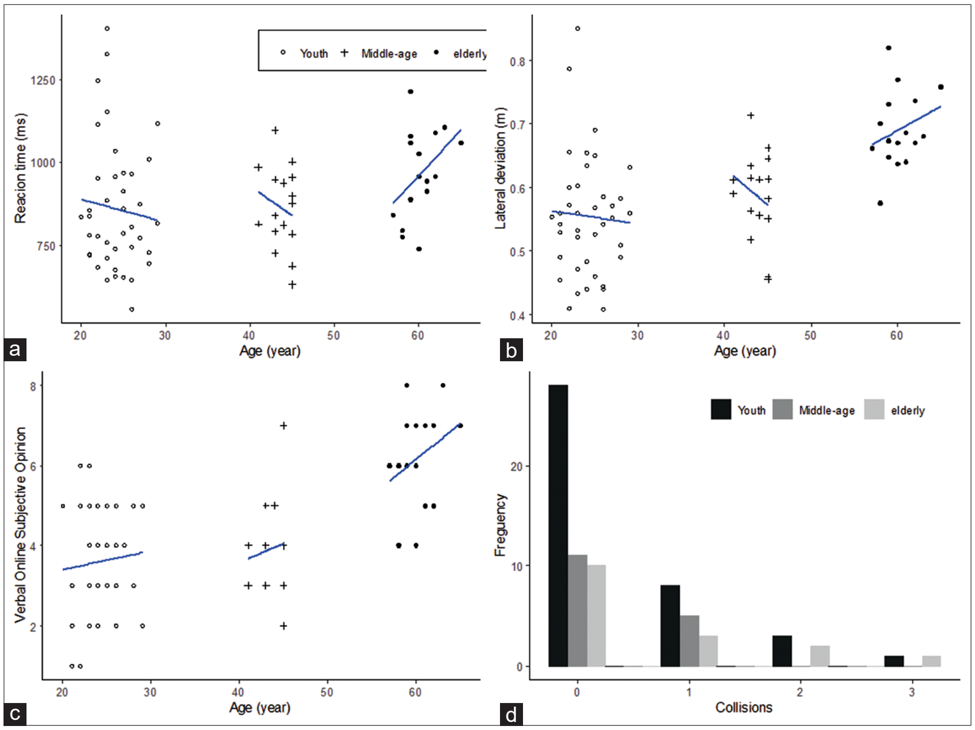

Figure 2: Scatter plot of study variables and least squared regression line. Part a) Reaction time against the age. Part b) Lateral deviation against the age. Part c) VOSO against the age. Part d) Collision frequency in age groups

Table 2: Univariate ANOVA test for the effect of age on study variables

Dependent variable	Mean squared	*F*	*P*
Reaction time			
Age	68,544	2.37	0.101
Residuals	28,882		
Lateral deviation			
Age	0.107	15.37	<0.001
Residuals	0.007		
Mental workload (VOSO)			
Age	39.26	24.41	<0.001
Residuals	1.61		

VOSO: Verbal online subjective opinion

Table 3: Relationship between study variables using Pearson correlation coefficient

Variable	*r*	*P*
Reaction time and vehicle lateral deviation	0.614	<0.001
Reaction time and VOSO scale	0.578	<0.001
Vehicle lateral deviation and VOSO scale	0.802	<0.001

VOSO: Verbal online subjective opinion

According to the results obtained, the elderly group had a higher lateral deviation and showed a poorer performance at this phase as well. In other words, the present study showed that the age affected significantly on the lateral deviation of vehicle among drivers. A study by Cantin *et al*., also showed that the workload perceived by the elderly drivers was greater than that of the young ones.[24] In a study by Rumschlag *et al*., it was observed that drivers' ages had a significant correlation with the amount of vehicle deviation as well as the percentage of the individuals who left the lane.[39] This observation is consistent with the results of the present study. Some reasons have been mentioned for this: driving is a complex task and requires great attention. The secondary driving tasks impose more mental workload on the driver. Makishita and Matsunaga state that a lot of driver's capacity is allocated to the hardness of such tasks as mental calculations during driving. Therefore, if the overall capacity of the driver is not sufficient, he will have a problem in his driving performance. He states that if the capacity left for the reaction is low, the performance will depend, to a great extent, on the conditions.[38]

Although the univariate ANOVA revealed that the effect of age on reaction time is not significant, the average reaction time of the elderly group was higher than that of the middle-aged and youth groups, and elderly drivers responded much slower to the pedestrians. Makishita and Matsunaga,[38] studied the effect of age and workload on young, middle-aged, and elderly drivers. They used reaction time to assess drivers' performances. Their study showed that when drivers performed mental calculations while driving, the reaction time for the elderly group was longer than that of the middle-aged group and for the middle-aged group longer than that of the young group. Thus, it can be deduced that the longer reaction time of the elderly drivers is associated with their greater perceived mental workload. The longer reaction time can be seen from different points of view. For example, it can be assumed that elderly drivers notice the pedestrians later than young and middle-aged drivers, their brains take longer to process the issue, and the motor command is issued later. This can be considered as a characteristic of aging. For example, Cicchino and McCartt, examined the impact of personality traits as predictors of risky driving on elderly people, and developed a model, in which personality traits of old people were used to predict risky situations.[40] Martin *et al*., examined the effect of driver's age and direction of pedestrians on the minimum distance needed to brake and avoid the collision. Their study showed that this distance was longer for the elderly group than that of the young group by 1.8 m. Moreover, the reaction time of the old drivers was longer than that of the young ones, and the difference in the reaction time was statistically significant. They stated that the decreased ability of older adults was probably due to a decrease in the speed of response initiation.[12] In many studies, it has been observed that brake reaction time increases with increasing driver's age.[14,16,18] In most of these studies, the longer reaction time of elderly drivers was attributed to the cognitive aspects and processing functions of the brain. In some studies, no difference was observed between the braking times of old drivers and other age groups.[17] Some studies also showed that the reaction speed of the elderly drivers was the same as that of the young drivers, although they took different strategies. For example, they have braked more often and more strongly and, thus, have been able to solve the problems of critical traffic events.[41] In the present study, there was no significant of effect of age on reaction time, but this variables amount was higher in elderly groups.

The unidimensional VOSO scale was used in this study to measure the self-report of the drivers' mental workload. For this scale, the greatest value, which represents the highest level of mental workload perceived by the drivers was related to the elderly age group. Moreover, the values of this scale were greater for middle-aged drivers than young ones. The greater values of this scale for the elderly and the middle-aged groups confirm the results of the reaction time and the vehicle lateral deviation obtained in the present study. In the examination of the three variables, i.e., the reaction time, the vehicle lateral deviation, and the VOSO scale, the highest value which represents the greatest mental workload of the drivers, was related to the elderly and the middle-aged group, respectively, and the young age group showed the least amount of mental workload. No study has yet been undertaken to assess the mental workload of drivers using a driving simulator and this VOSO scale.

The use of this scale is simple and inexpensive, and it can be used to assess the mental workload of individuals. In a study by Antin and Wierwille, It was revealed that the VOSO scale had a positive correlation with the reaction time and the workload level.[42] They suggested that future research should pay more attention to this scale. This scale has also been used in the study of the effect of mental workload on simulated air traffic control by Marchitto *et al*., in their study, the VOSO scale was used to assess the mental workload and the self-reported mental workload.[43] In a study by Charkhandaz Yeganeh *et al*., the validity and reliability of the VOSO scales were confirmed and it was reported that there is a correlation between these scales and the long reaction time.[37] In the present study also positive correlations were calculated between VOSO score and amounts of reaction time and lateral deviation.

The other important variable in the present study is the number of collisions. The result from the study by Bélanger *et al*., using a driving simulator, showed that older drivers had a higher risk of accidents in situations where more consistent reactions were required. Their study revealed that in situations where the simultaneous use of steering-wheel and the brake pedal was required, elderly drivers tended significantly to have more accidents.[44] Some studies suggest that cognitive impairments, especially those related to the field of attention, have the strongest correlation with motor vehicle accidents caused by elderly drivers.[41,45] These studies have shown that old drivers have a higher rate of accidents at intersections, which is the result of difficult and complex driving conditions, and a higher momentary mental workload at intersections. Some studies have also shown that elderly drivers have less ability to quickly detect an impending accident. These studies have argued that the reason for this, in many cases, is the inability of the elderly drivers to determine the speed and the distance of other vehicles.[24] These findings are approximately consistent with the results of the present study. The results of collisions indicate that the drivers were almost able to timely control the vehicle to avoid collision with pedestrians. Based on the results associated with this variable, although the difference of collision number among three study groups was not significant, the best driving performance was related to middle-aged and young-aged groups, respectively. We can interpret the result through some assumptions. It seems that more investigations in this area are needed.

Finally, about the correlations between variables, some points are important. There was a significant and positive correlation between the reaction time and the vehicle lateral deviation. If there is a proper correlation between these two variables, either of them can be used to assess the driving performance and the workload using a functional method. The validity of both methods to measure the drivers' mental workload has been examined and verified by other studies.[8] Another important finding was the high positive correlation between VOSO score and amounts of lateral deviation and reaction time that was similar to some other studies.[37,42]

And finally, this study had some limitations. One of these limitations was related to sample size; another was related to access to elderly drivers with the age of higher than 65 years old. Moreover, our scenarios for the study were limited because of technical reasons.

Conclusion

The present study showed that the driving performance of the elderly group was poorer than that of middle-aged and young ones. In this regard, lateral deviation and mental workload were affected significantly by age in the present study. Results showed that with increasing age in the elderly group, the amount of mental workload, vehicle lateral deviation and reaction time were increased. Although in this study, the age had not significant effect on reaction time and number of collision, the amount of these two variables was higher in the elderly group compared to middle-aged and young groups. Another important finding of this study was the significant positive correlations between reaction time, vehicle lateral deviation and VOSO amounts. This finding showed that it can use each of these variables for measuring drivers' mental workload.

One of the most positive aspects of the study was using the reaction to the appearance of pedestrians that it is had not been used in the previous study in Iran. Researchers offer following ideas for future studies: Using physiological tools to measure the mental workload of drivers in different age groups along with functional and self-reported tools, study the reasons that could increase the reaction time of elderly drivers, the study of imposed mental workload of drivers with different age groups by different driving scenarios in terms of environment complexity.

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Conflicts of interest

There are no conflicts of interest.

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