Factors Associated with Driving Performance of Older Drivers

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A 2-year study of older drivers was conducted at the University of Nebraska to develop and evaluate methods for improving the safety of older drivers. During the first year, data on several characteristics including driving performance of older drivers were collected. The correlation between driving performance and measured characteristics was investigated to provide a basis for the design of the countermeasures, which were evaluated in the second year. The results of the analysis of the factors associated with the driving performance of older drivers are presented. Several factors relative to the physical and mental status of 105 drivers between the ages of 65 and 88 were measured. In addition, their driving knowledge and on-street driving performance were evaluated. Pearson product-moment correlation coefficients were computed to measure the relationships between on-street driving performance and the other factors. In addition, stepwise multiple regression analysis was used to determine the combination of factors that accounted for the most variability in the on-street driving performance. A number of factors associated with vision, visual perception, cognition, and driver knowledge were found to correlate significantly with the driving performance of older drivers. The results of the analysis suggest that a number of methods can improve the safety of older drivers; among them are (a) physical therapy to improve range of motion, (b) therapies or exercises to improve visual perception and cognition, and (c) driver education to increase driving knowledge pertinent to the accident situations in which older drivers are overinvolved.

During the past few decades research has provided insight into some of the deficiencies in the abilities of older people that affect their driving performance. As related to the driving task, these deficiencies may be classified into five categories:

- *Sensory*, which includes any deficiency in human senses that may affect the amount or quality of information received while driving;
- *Perceptual*, which is related to the human ability to identify objects presented while driving;
- *Cognitive*, which is related to the human ability to match the perceived information with past experience and decide on the proper action to be taken;
- *Physical,* which is related to the functional ability of the human body to perform the driving task; and
- *Driving knowledge*, which is related to the driver's understanding of how to drive in response to prevailing roadway and traffic conditions.

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These factors have been evaluated as possible discriminators between young and old drivers. All of them have been found to exhibit some age differences (*1*,*2*). However, the degree of discrimination was not the same for all factors. It was dependent on the type of task and the age difference between the younger and older drivers being considered. Because driving is a highly visual task, it is important to note that many adults tend to have significant deficits in visual functioning (*3*). However, contrary to intuition, published research has failed to establish a link between vision and driving in elderly persons (*4–6*). Considerable published evidence suggests a decline in the cognitive functioning of aging individuals (*7*,*8*). Many studies have shown that intact cognition is a necessary component of safe driving (*9–11*). Also, people of the same age usually exhibit differences with respect to these five factors for reasons other than the age. Consequently, age alone has not been found to be a reliable indicator of driving ability.

A 2-year study of older drivers was conducted by the University of Nebraska to develop and evaluate methods to improve the safety of older drivers. During the first year, the problems of older drivers were analyzed to provide a basis for the design of the countermeasures. The results of the analysis of the factors associated with the driving performance of older drivers are presented in this paper.

METHODOLOGY

Several factors relative to the physical and mental status of 105 drivers between the ages of 65 and 88 were measured. In addition, their driving knowledge and on-street driving performance were evaluated. Pearson product-moment correlation coefficients were computed to measure the relationships between on-street driving performance and the other factors. In addition, stepwise multiple regression analysis was used to determine the combination of factors that accounted for the most variability in the on-street driving performance.

SUBJECTS

The subjects who participated in the study were active individuals who drive regularly. The average age of the 105 drivers was 71.4 years. Fifty-four were women, with an average age of 70.5 years, and 51 were men, with an average age of 72.2 years. The distribution of the subjects by age and gender is shown in Table 1. Thirty-six of the subjects have taken a driver education course within the past 10 years. All of the subjects

TABLE 1 Distribution of Subjects by Age and Gender

Age	Male	Female	Total
65 - 69	19	22	41
70 - 74	17	24	41
75 - 79	9	6	15
80 - 84	4	2	6
85 - 89	2	0	2
Total	51	54	105

were volunteers, and they were each paid $25 for their participation in the study.

FACTORS

The characteristics of older drivers evaluated in this study were vision, visual perception, cognition, reaction time, range of motion, and driving knowledge. The methods used to measure each of these factors are described in the following.

Vision

Keystone telebinocular testing device was used to measure the vision of each subject. These measurements included far and near acuity, depth perception, left and right peripheral vision, color vision, and lateral and vertical phoria. Although these measures were recorded, they were not expected to be good correlates of driving (*6*).

Visual Perception

The motor-free visual perception test (MVPT), designed and standardized on children by Colarusso and Hammil (*12*), was used in this study to assess the visual perception of older drivers. The test is composed of 36 questions, divided into the five groups, that assess the following aspects of visual perception:

1. *Spatial relationship*, which is the ability orient one's body in space and perceive the positions of objects in relation to oneself and other objects;
2. *Visual discrimination*, which is the ability to discriminate dominant features in different objects;
3. *Figure-ground,* which is the ability to distinguish an object from its background;
4. *Visual closure*, which is the ability to identify incomplete figures when only fragments are presented; and
5. *Visual memory,* which is the ability to recall dominant features of one stimulus item or to remember the sequence of several items.

A modified version of MVPT has been used to evaluate brain-damaged people (*13*), but the use of MVPT to evaluate elderly people has not been reported in the literature. However, because the test does measure the aforementioned cognitive factors, it was used in this study.

The MVPT was administered by occupational therapists according to the standard procedure. Two scores were obtained for each subject for each of the five visual-perception measures. One was the mean time required for the subject to answer the questions pertaining to the given measure (response-time score), and the other was the number of questions answered correctly (error score). Overall response-time and error scores were also computed.

Cognition

Three tests were used to measure the cognitive ability of a subject: the mini-mental state (MMS) examination, the trail-making test Part A (TMA), and the trail-making test Part B (TMB). Because other factors besides cognition were being tested, the cognitive tests had to be restricted to MMS, TMA, and TMB.

MMS is a simplified cognitive status examination devised by Marshal et al. (*14*). Compared with other cognitive performance tests such as Withers and Hinton's or Wechsler adult intelligence scale, MMS concentrates only on the cognitive aspects of mental functions. It excludes questions concerning mood, abnormal mental experiences, and the form of thinking, but includes questions on orientation. Normal, healthy elderly people have been found to score well on the MMS (*15*), and it has been found to be a predictor of driving (*1*).

TMA and TMB are both composed of 25 circles distributed randomly on an 8- × 11½-in. sheet of white paper. In TMA, the circles are numbered randomly from 1 to 25. The time required for the subject to correctly draw a line connecting the 25 circles in numerical order is measured. In TMB, there is either a number (from 1 to 13) or a letter (from A to L) written inside each circle, and the time it takes the subject to correctly draw a line connecting the circles in alternate numerical and alphabetical order (from 1 to A to 2 to B, etc.) is measured. TMA is a general measure of visuospatial scanning ability and motor sequencing skills. TMB requires some abilities in addition to those required for TMA. Alternating between numbers and letters requires more language skills of the subject and the ability to switch flexibly between numbers and letters. The tests were found to be 81 percent effective in diagnosing brain-damaged subjects and were also found to be sensitive to age (*7*).

Reaction Time

The brake reaction times of the subjects were measured with a Doron L225 driving simulator. The stimulus was a display composed of two rectangular red lights, each 2×3 cm, mounted 4 cm apart on the dashboard of the simulator. The lights flashed in alternating fashion. When both lights turned on at the same time, the subject was to release the gas pedal and push the brake pedal as fast as possible. Six trials were obtained from each subject, and the mean was taken to represent subject's brake reaction time.

Range of Motion

Flexibility is an essential component of the physical fitness of older people (*2*). Movement of the upper extremities plays a vital role in driving (*16*). Decreased head and neck mobility impair the ability of the older driver to perform driving tasks such as scanning the rear, backing, and turning the head to observe blind spots (*17*). Complex arm, leg, and head movements while driving tend to be limited among the elderly (*18*). In a survey of the problems of the elderly, 21 percent of the older drivers reported difficulty in turning their heads and looking to the rear when driving (*19*).

Range-of-motion measurements were taken both in the clinic and in the car. The measurements in the clinic were taken with the subject seated upright in a straight-backed chair with both feet on the floor. The following range-of-motion measurements were taken in the clinic: neck flexion, neck extension, neck rotation to the left, neck rotation to the right, neck lateral bend to the left, neck lateral bend to the right, left shoulder flexion, right shoulder flexion, trunk rotation to the left, and trunk rotation to the right.

The in-car measurements were taken with the subject seated behind the steering wheel. The subject's seat belt was fastened, and the subject's hands were in their normal driving position on the steering wheel. The following range-of-motion measurements were taken in the car: neck flexion, neck extension, neck rotation to the left, neck rotation to the right, neck lateral bend to the left, and neck lateral bend to the right. Three measurements of each motion were taken, and the average of the three was used.

Driving Knowledge

To drive safely, drivers must know how to drive their vehicles under a variety of roadway and traffic conditions. In addition, they must know the rules of the road, the traffic laws and regulations, and the meanings of the traffic control devices. Previous studies have found that older drivers are often less knowledgeable about driving than younger drivers (*20,21*). McCoy et al. found that scores on the driving-knowledge portion of the Nebraska driver's license examination were lower for older drivers, and the average score of drivers over 75 years old was below the 80 percent required to pass the test (*22*).

A 50-question multiple-choice test was used to measure the driving knowledge of the subjects. The test was designed to determine their driving knowledge pertinent to the types of accidents in which older drivers in Nebraska were overinvolved. The distribution of the questions on the test was according to the distribution of collision types and contributing circumstances reflected in the accident experience of older drivers in Nebraska. The distribution of the test questions is given in Table 2. For example, 25 of the 50 questions pertained to left-turn collisions involving failure to yield the right of way. The percentage of the questions answered correctly was used as the measure of driving knowledge.

DRIVING PERFORMANCE

The driving performance of the subjects was evaluated using the on-street driving performance measurement (DPM) technique developed at Michigan State University (*23*). This technique provides a systematic approach to the design of an on-street DPM route and a reliable method for rating driving performance as satisfactory or unsatisfactory on the basis of observable driver behavior patterns composed of search, speed control, and direction control. The pilot studies conducted in Michigan showed that the DPM technique is a reliable and valid measure of safe and skillful driving. The subjects were evaluated by a driver education expert trained and experienced in the use of the DPM technique. The evaluator scored the driving performance of the subjects while riding with them in the front passenger seat of the vehicle. The evaluator did not have any information on the performance of the subjects in the other tests. The evaluation was done two times. Within-evaluator reliability was established through a *t*-test done on the score of the two road tests. The two road test scores were not different from each other. Similarly, because two evaluators were used, between-evaluator reliability was also established through a *t*-test. Road test scores on a sample of drivers evaluated by each of the evaluators were tested against each other, and they showed to be insignificant. The subjects drove their own vehicles.

DPM Route

The DPM route was designed to evaluate the subjects in the situations that are most often involved in the accidents of older drivers. The results of an analysis of accidents in Nebraska indicated that older drivers were overrepresented in left-turn and right-angle collisions at controlled intersections in urban areas on weekdays between 9:00 a.m. and 3:00 p.m. (*14*). Therefore, the route featured the evaluation of the subjects at urban intersections.

The DPM route was a 19-km circuit in Omaha, Nebraska. The driving performance of the subjects was evaluated at seven intersections on the route. The subjects were required to make left turns at five of the intersections and right turns

TABLE 2 Distribution of Driving Knowledge Test Questions

Contributing Circumstance	Accident Type								Total
	Right Angle	Rear End	Side Swipe	Head On	Left Turn	Other Turn	Right Turn	Pedestrian	
Failure To Yield	4[a]/2[b]		1/1		50/24	4/2	1/1	4/2	64/32
Disregarded Traffic Signal	10/4			1/1	1/1				12/6
Improper Turn Signal						1/1			1/1
Made Improper Turn			1/1	1/1	4/1	1/1			7/4
Following Too Close		11/5							11/5
Improper Lane Change			5/2						5/2
Total	14/6	11/5	7/4	2/2	56/27	5/3	1/1	4/2	100/50

[a] Percent of older-driver accidents.

[b] Number of driving-knowledge test questions.

at the other two intersections. Four of the left turns were made from left-turn lanes on four-lane divided arterial streets in suburban areas and one was made from a left-turn lane on a two-lane two-way street in an outlying business district. Two of the left turns were controlled by protected/permitted left-turn signal phases, two were controlled by permitted left-turn signal phases, and one was uncontrolled. One of the right turns was on a turning roadway at a signalized intersection on a four-lane divided arterial street in a suburban area. The other right turn was made from a stop-sign controlled approach at an intersection of two, two-lane two-way local streets in a residential area. The speed limits were from 35 to 45 mph on the arterial streets and 25 mph in the outlying business district and residential area.

Evaluation

Each of the seven turning maneuvers evaluated was divided into three segments: (a) the approach to the intersection, (b) the turning maneuver itself, and (c) the departure from the intersection. The performance of the subject in each segment was evaluated as being satisfactory or unsatisfactory. One point was given for each "satisfactory" score and zero points were given for an "unsatisfactory" score. Therefore, the best driving performance score that a subject could receive for each trip around the route was 21 points, and the worst was 0 points. The criteria for determining satisfactory or unsatisfactory performance were in terms of the subject's search pattern and control of the vehicle's speed and direction.

The subjects made two trips around the route. Therefore, 42 was the maximum score that they could receive. The measure of driving performance used in the analysis was the driving performance score expressed as a percentage of 42. It usually took the subjects about an hour to complete two trips around the route.

RESULTS

Correlation Analysis

The data were initially checked for possible outliers, and the check was followed by a correlation analysis. The results of the correlation analysis are presented in Table 3. Among the vision factors, depth perception and right visual field showed the highest correlations, of .35 and .22, respectively. They were also the only significant correlations (p-values $< .05$) with the driving performance among the vision factors.

Among the visual perception factors, the following scores were correlated significantly (p-values $< .05$) with the driving performance: spatial relationships error score (.21), visual discrimination error score (.26), visual discrimination response-time score (-0.22), figure-ground response-time score (-0.28), visual closure response-time score (-0.24), visual memory response-time score (-0.38), overall error score (.26), and

TABLE 3 Correlation Between Driving Performance and Factors

Factor	Correlation Coefficient	P-Value
Vision		
Far Acuity	0.18	0.0577
Near Acuity	0.15	0.1347
Depth Perception	0.35	0.0002
Right Visual Field	0.22	0.0238
Left Visual Field	0.12	0.2354
Color Vision	0.07	0.5016
Lateral Phoria	-0.03	0.7681
Vertical Phoria	0.16	0.1001
Visual Perception		
Spatial Relationships Error Score	0.21	0.0276
Spatial Relationships Response Time	-0.14	0.1591
Visual Discrimination Error Score	0.26	0.0071
Visual Discrimination Response Time	-0.22	0.0250
Figure-Ground Error Score	0.05	0.5967
Figure-Ground Response Time	-0.28	0.0036
Visual Closure Error Score	0.18	0.0595
Visual Closure Response Time	-0.24	0.0113
Visual Memory Error Score	0.10	0.3059
Visual Memory Response Time	-0.38	0.0001
Overall Error Score	0.26	0.0079
Overall Response Time	-0.32	0.0008
Cognition		
Trail-Making Test Part A	-0.03	0.7329
Trail-Making Test Part B	-0.42	0.0001
Mini-Mental Status Exam	0.24	0.0123
Brake Reaction Time	-0.15	0.1182

(continued on next page)

overall response-time score (−0.32). As expected, the negative correlations were associated with the response-time scores and the positive correlations were associated with the error scores.

Among the cognitive measures, TMB and MMS showed the highest correlations, of −0.42 and 0.24, respectively. They were also the only significant ones. In fact, it is interesting to note the difference in correlation between TMA and TMB. For some unexplainable reasons TMB has turned out to be a reasonably decent predictor of driving performance. The main difference between the two tests is that TMB had both alphabets and numbers in the map that the subjects traced, whereas TMA had only numbers in the map. Further research is needed in this area. TMB had the highest correlations of any of the factors included in the analysis.

The driving knowledge test score (.27) was also significantly correlated with driving performance.

None of the range-of-motion measures was significantly correlated with the driving performance. All of these measures had relatively low correlations except the in-clinic measures of trunk rotation to the right (.17), trunk rotation to the left (.14), and neck lateral bend to the right (.15).

Other factors included in the analysis were age, gender, and whether the subject had a driver education course within the past 10 years. None of these had significant correlations with driving performance.

TABLE 3 *(continued)*

Factor	Correlation Coefficient	P-Value
In-Clinic Range of Motion		
Neck Flexion	0.08	0.4290
Neck Extension	0.10	0.2875
Neck Rotation to the Left	0.01	0.9161
Neck Rotation to the Right	-0.07	0.4507
Neck Lateral Bend to the Left	0.03	0.7617
Neck Lateral Bend to the Right	0.15	0.1156
Shoulder Flexion to the Left	0.08	0.4306
Shoulder Flexion to the Right	0.13	0.1724
Trunk Rotation to the Left	0.14	0.1562
Trunk Rotation to the Right	0.17	0.0744
In-Car Range of Motion		
Neck Flexion	0.04	0.6822
Neck Extension	0.13	0.1803
Neck Rotation to the Left	-0.11	0.2425
Neck Rotation to the Right	0.08	0.4087
Neck Lateral Bend to the Left	-0.04	0.6798
Neck Lateral Bend to the Right	-0.01	0.8868
Driving-Knowledge Test Score	0.27	0.0053
Other		
Age	-0.11	0.2651
Gender	0.04	0.7087
Taken Driver Education Course Within Past 10 Years	0.04	0.7100

Multiple Regression Analysis

The results of the stepwise multiple regression analysis are presented in Table 4. All factors investigated in this study were included the stepwise procedure of the regression analysis at the .05 level of significance for the entry and removal of variables from the model. TMB, trunk rotation to the right, TMA, overall visual perception response-time score, and spatial relationship error score were the only significant factors. Together they accounted for 45 percent of the total variability in the driving performance. According to the signs of the regression coefficients in the model, better driving performance was associated with better cognition as measured TMA and TMB, better range of motion in trunk rotation, and visual perception.

DISCUSSION OF RESULTS

Vision

Depth perception and peripheral vision are among the most important aspects of vision needed for safe driving. Depth perception is important for estimating distances, especially those of moving objects. Driving requires the continuous estimation of distances. Since many of the cues in driving come from the roadside, peripheral vision is also helpful. Narrow visual fields limit the ability of the driver to receive timely information. Rotation of the head and eyes to compensate for deficiencies in peripheral vision increases the time required to receive the information. Both of depth perception and peripheral vision showed significant correlations with the driving performance of the older drivers.

TABLE 4 Regression Analysis Summary

Factor	Sign of Regression Coefficient	Partial R^2	Model R^2	F-Value	P-Value
Trail-Making Test Part B	-	0.23	0.23	19.80	0.001
Trunk Rotation To The Right	+	0.07	0.30	9.82	0.028
Trail-Making Test Part A	-	0.05	0.35	7.90	0.0078
Visual Perception Response-Time Score	-	0.07	0.42	10.92	0.0013
Spatial Relationships Error Score	+	0.03	0.45	5.15	0.0256

Visual Perception

Better driving performance was associated with better visual perception, especially with visual memory and figure-ground discrimination. Visual perception is an indicator of the ability to manipulate objects so that they are recognized quickly and accurately. Compared with the correlations of the vision factors, visual perception has a greater bearing on driving performance among older drivers. Some older drivers may have good vision but cannot use it effectively.

Cognition

The results of the analyses indicate the importance of the general cognitive state of older drivers in relation to their ability to drive safely. Most highly correlated with driving performance were the aspects of cognition measured by the TMB and MMS tests such as language skills, orientation, memory, attention, and ability to follow verbal and written instructions.

Range of Motion

None of the range-of-motion factors correlated significantly with the driving performance. These factors are important for driving, especially the neck and trunk rotation. However, it is not surprising that these factors did not correlate significantly with the driving performance as measured in this study. These factors are most important for safe driving in high-volume, high-speed traffic such as that on a freeway. The lane-changing, passing, and collision avoidance maneuvers required under these conditions demand more head rotation. But older drivers usually avoid driving under these conditions. Therefore, the DPM route did not include these conditions.

Driving Knowledge

The driving knowledge of older drivers showed a significant and reasonably high correlation with their driving performance, which appears logical. Knowing how to drive properly is a prerequisite to driving properly.

Other Factors

Age and gender did not have large or significant correlations with driving performance. Of course, only drivers between the ages of 65 and 88 were evaluated. The narrow age range may account for the lack of correlation between age and driving performance. It is noteworthy that chronological age did not predict driving performance. This would help argue against age cutoffs for licensing. But the subjects were about evenly divided between men and women. Therefore, gender may not be a factor in the driving performance of older drivers.

With respect to driver education, whether the subject had taken a driver education course within the past 10 years had a very small correlation with driving performance. However, most of the subjects who had taken a driver education course within the past 10 years had taken it more than 5 years ago. Consequently, the results cannot be considered applicable to the drivers who had taken a course within the past 5 years.

CONCLUSION

A number of factors associated with vision, visual perception, cognition, and driver knowledge were found to correlate significantly with the driving performance of older drivers as measured by the on-street DPM technique. The results of the analysis suggest a number of methods for improving the safety of older drivers. The positive correlation found between driving performance and the vision factors of depth perception and peripheral vision indicates that older drivers need to be aware of ways to compensate for deficiencies with respect to these factors. Search patterns and maintenance of margins of safety that compensate for these deficiencies are typically included in education courses for older drivers. Therapies designed to improve the visual perception of older drivers are suggested by the correlations found between driving performance and visual perception. Likewise, measures designed to improve cognition are indicated as possible ways to improve the driving performance of older people.

The results of the regression analysis indicate that physical therapy designed to improve range of motion may benefit older drivers. A driver education program designed specifically to improve spatial scanning, visual information processing skills, and cognitive functioning skills may improve the driving performance of the older driver. A caveat is in order here: although this study had 105 subjects, when distributed over 40 factors the number of subjects per factor became low. Therefore, a validation study is definitely needed before any generalization can be made.

As a result of the analysis, the countermeasures designed for evaluation during the second year of the research were physical therapy, perceptual therapy, driver education, and traffic engineering improvements. The results of the evaluation of the effects of these countermeasures on the performance of older drivers are reported elsewhere (*24*).

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