A METHOD FOR ASSESSING THE DRIVING ABILITY OF THE ELDERLY AND THOUGHTS ON ITS SYSTEMATIZATION

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Traffic accidents caused by elderly drivers and resulting in personal injury or death have nearly tripled over the last decade; the elderly now total more than 40% of all traffic fatalities. Serious accidents caused by drivers with senile dementia have increased and the issue of driver license renewal has become a major public concern. Although driving ability decreases with advanced age, few elderly people recognize the decline in their own visual, cognitive and decision performance; this lack of awareness is a major cause of accidents. To reduce the number of accidents involving elderly drivers, it is critical that, beginning early in middle age, drivers undergo regular assessments of driving ability (particularly visual, cognitive and decision performance), are aware of their own abilities and driving aptitude, and maintain and improve their driving ability through reeducation and training.

Currently, the driving ability of elderly drivers is assessed through National Police Agency driver aptitude tests (written tests of driving behavior, decision performance and temperament, and computerized tests of factors such as reaction time, reaction consistency and steering) administered during elderly driver workshops conducted at the time of driver license renewal. Because these tests do not incorporate actual driving situations, however, they offer an incomplete assessment of visual, cognitive and decision performance while driving. For this research, video simulations of actual driving situations were created and used in developing an experimental system for comprehensively measuring functions essential for safe driving such as visual performance (in particular, the narrowing of the useful field of view caused by aging) as well as cognitive and decision performance (visuo-spatial perception at intersections and the decline in attentiveness). This paper describes the proposed system for measuring driving ability, the method of measurement, and sample results for driving ability in the elderly.

Key Words: Traffic accidents, Elderly drivers, Driving ability, Measurement and evaluation, Simulators

1. INTRODUCTION

As Japan becomes the first “super-aged” society in the developed world, the number of accidents caused by elderly drivers is rapidly increasing. For the past few years, the elderly have accounted for more than 40% of all traffic fatalities, a very high percentage relative to other age groups. The growing number of serious accidents caused by healthy elderly drivers with reduced cognitive ability, as well as elderly drivers with suspected or diagnosed dementia, has drawn public attention to the issue of driver license renewal.

Although advanced age is generally accompanied by a decline in physical and mental attributes related to cognition, decision-making and mobility, few elderly people recognize how far their visual, cognitive and decision performance have declined since their youth. This lack of awareness is a major cause of accidents. To reduce the number of accidents involving elderly drivers, it is extremely important that drivers, beginning early in middle age (say, in their 50s), regularly check their driving ability (particularly visual, cognitive and decision performance) to gain a better awareness of their own abilities and driving aptitude, as well as work to maintain and improve their driving ability through reeducation and training.

The objective of the current research is to incorporate situations that closely approximate actual driving into the development of a system for comprehensively measuring visual, cognitive and decision performance, which are essential for recognizing the various objects encountered while driving and for ensuring safe driving. This system seeks to contribute not only to driving aptitude checks and greater self-awareness of declining driving ability among the elderly, but also to help the elderly...
maintain the driving ability of their youth through reeducation and training.

This paper first looks at accidents involving elderly drivers, their decline in driving ability, and issues with conventional methods of assessing driving ability. Next, it introduces the proposed measurement system and methodology, providing sample results for driving ability among the elderly. Finally, it presents a simplified measurement system intended for use at driving schools.

2. ACCIDENTS AND DECLINING DRIVING ABILITY AMONG ELDERLY DRIVERS

A review of the statistical data for accidents and traffic violations involving the elderly enables the following summary of common patterns:

1. Most accidents caused by elderly drivers occur at intersections; an especially high number occur at intersections without stoplights.
2. Many vehicle-to-vehicle accidents are either offset frontal or right-turn collisions.
3. Single vehicle accidents tend to be either roadway departures or collisions with structures at curves.
4. Common violations leading to accidents include failure to come to a complete stop, running red lights and impeding the right of way of others.

These accidents and violations, which occur more commonly with advanced age, are closely related to driving behaviors characteristic of elderly drivers such as errors of cognition or decision, that is, to the decline in driving ability that comes with age.

Elderly drivers experience a marked decline in their ability to attend simultaneously to multiple objects in high-traffic situations and to rapidly grasp changing conditions (cognitive and decision performance). In addition, they have greater difficulty maintaining appropriate attention levels for long periods of time.

With regard to visual performance, which plays a large role in recognition, a reduced range of vision while driving means peripheral objects are more easily overlooked; reduced dynamic and kinetic visual acuity and distance perspective (depth perception, etc.) mean spatial relationships are more easily misjudged. Another important characteristic is that objects more frequently go unseen in low-light conditions such as twilight and nighttime due to reduced night visual acuity (night myopia) and dark adaptation. Furthermore, since roughly 70% of those in their sixties and 80-90% of those in their seventies have age-related cataracts, there is concern that significantly reduced static visual acuity may lead to accidents not only in low-light conditions but also under glare conditions (caused, for example, by the setting sun or oncoming vehicle headlights).

3. PROBLEMS WITH CONVENTIONAL ASSESSMENTS OF DRIVING ABILITY

Given that 70-80% of accidents are caused by errors of cognition or decision, it is important when assessing driving ability to emphasize cognitive and decision performance, including visual performance. Major aspects of cognitive and decision performance include visuo-spatial abilities (such as dynamic visual acuity, field of view and depth perception) and various attentional functions (such as focal attention, divided attention, sustained attention).

Methods for assessing the driving ability of elderly drivers now in use at driving schools include both written and computerized National Police Agency driver aptitude tests (Fig. 1). The former evaluates attentiveness and judgment by having examinees find targets in photographs of driving scenes and select proper responses. The latter uses a computer screen to assess some aspects of driving ability using simple and selective reaction times to test primarily for reaction and decision-making speed and to check reaction consistency and relaxation response.

The results of both tests serve primarily as a guide for safe driving instruction and are inadequate for reminding elderly drivers of dangerous driving situations or promoting awareness of safe driving.

Fig. 1 National Police Agency CRT driving aptitude test (Computer-based)
Past research on driving ability assessment has largely looked at ways to measure driving operations and behavior in emergency avoidance situations using driving simulators. Because such assessments focus on driving operations and behavior when avoiding unexpected emergencies, they are ill suited for measuring or assessing cognitive and decision performance during normal driving. It is important to find a means of assessing cognitive and decision performance in situations, like everyday driving, when various objects require attention and multiple decisions must be made not in isolation but over a continuous period of time.

At the same time, while field of view (static field of view and useful field of view), kinetic and dynamic visual acuity (KVA and DVA), depth perception, and glare are well-known as important aspects of visual function indispensable when driving, current workshops for the elderly measure only KVA, dark adaptation time and ordinary static visual acuity. Here, DVA measures the tracking of objects moving from side to side while KVA measures the tracking of objects approaching the eye from a distance. Useful field of view, believed to be the most important factor related to accidents by the elderly, is not tested and it is rarely measured using driving simulations. Furthermore, the prevalence of age-related cataracts in people over sixty years of age creates a need to measure static visual acuity under evening or nighttime driving conditions when it is difficult to see. Such measurements will be particularly important in checking for the presence and degree of cataracts.

4. DRIVING ABILITY MEASUREMENT SYSTEM

In consideration of the accidents caused by elderly drivers, their decline in driving ability and their cognitive and decision performance errors, the authors developed a comprehensive system for measuring visual, cognitive and decision performance, factors indispensable for safe driving. The basic principles are outlined below.

(1) Main elements of the system include simulated driving images that closely approximate actual driving situations and a driving simulator that enables replication of driving operations (steering, accelerating, braking). The simulated driving images cover a variety of driving situations (urban locations, highway driving, driving school courses, etc.) and can be replayed at will. The timing of the appearance of objects like traffic signals, vehicles and pedestrians can be controlled, and the degree of difficulty (driver workload) adjusted flexibly.

(2) Measurements are made of visual functions indispensable for driving such as field of view (static field of view and useful field of view), kinetic and dynamic visual acuity (KVA and DVA), depth perception and, to address age-related cataracts, static visual acuity. The useful field of view measured by the system, in keeping with the definition used by Mackworth (1965, 1976), is understood to be “the scope of the useful or functional peripheral domain available when performing a visual task (a subset of the peripheral visual field).” It is not a measurement of the static or dynamic visual field with the fixation point (fovea) under no-load conditions, but of the field of view when the fixation point (fovea) is subjected to load. Measuring field of vision requires displaying the visual target over a broad viewing angle. Measuring KVA and depth perception requires the ability to display depth in three dimensions. Measuring static visual acuity to address age-related cataracts requires measurements under low light and glare. Also, as an indicator of attentional function, cognitive and decision performance is evaluated by measuring driving performance (task achievement rate, time required, etc.) in situations (like at intersections) where accidents involving the elderly frequently occur.

Figure 2 indicates the composition of the driving ability measurement system based on the basic principles above. The system is made up of a driver’s seat (steering

![Fig. 2 Composition of the driving ability measurement system](image-url)
wheel, accelerator, brake), a curved screen (140° horizontal), three projectors and a processing unit.

When measuring visual function, one projector displays simulated driving images on the center of the screen while the remaining two projectors display visual targets, used to confirm range of view and the like, on either side. Visual targets include simple marks or Landolt rings and vary with the aspect of visual function being measured. To provide visual targets with the appearance of three-dimensional depth as well as planar breadth, the two projectors are equipped with orthogonal polarizing filters and subjects wear polarizing glasses.

Conventional single-function measurement devices (KVA meter, depth perception meter) display depth in visual targets by varying the actual display distance optically or by physically moving the target itself. In order to measure multiple aspects of visual function with a single system, the simulator was designed for three-dimensional display.

To evaluate the cognitive and decision performance of elderly drivers (attention to multiple objects, ability to grasp position relative to objects, decision-making ability, etc.), simulated driving images are displayed across a wide-field screen using three projectors and various aspects of driving performance at intersections, etc. are measured.

5. METHOD OF MEASURING DRIVING ABILITY AND SAMPLE RESULTS

This section describes the measurement method and sample measurement results. The first measurements of visual function performed are of static field of view and useful field of view.

To measure static field of view, a fixation point (●) is displayed at the center of the screen. While subjects gaze at the fixation point, visual targets are displayed every 70msec (ten times) at random locations in the vicinity (within a 140° horizontal and 70° vertical range of the fixation point). Subjects are asked whether they visually detected each visual target (●) and their static field of view is evaluated by the rate of detection (number of targets detected/number of displays).

Figure 3 illustrates the method for measuring useful field of view. In order that this measurement subject the fovea to load, simulated driving images are displayed at the center of the screen rather than a fixation point (●). Subjects are asked to focus on these images, being careful when performing driving operations to avoid striking the people and vehicles that appear, while detecting visual targets that are displayed every 70msec as with static field of view. The simulated driving images are composed of numerous driving situations with varying levels of driver workload; when turning left or right at intersections, drivers must pay attention to traffic signals, other vehicles, and the presence and proximity of pedestrians. Because subjects’ gaze direction strays widely from front and center when turning left or right, objects (oncoming vehicles or pedestrians) requiring intentional attention (that is, objects that should be watched) are made to appear, and visual targets (●) displayed to either side of the gaze direction. Failure to watch the objects requiring attention results in contact with oncoming vehicles or pedestrians and indicates a failure to concentrate on safe driving, so measurement data is invalidated in such cases. Because driving accidents are related to how quickly one can detect, or not overlook, objects that appear in the vicinity of the object one is watching, detection rate is used to evaluate this measure in the same way as with static field of view. In light of the burden on the elderly, when measuring useful field of view, displays are limited to a total of 20 times.

Figure 4 indicates sample measurements of static and useful field of view, based on test results for the young (20 subjects in their twenties) and the elderly (20 subjects in their sixties). Little difference was found among the young between the results with and without driving operations. Among the elderly, however, the detection rate was notably lower with driving operations (useful field of view) than without (static field of view), indicating a marked reduction in field of view when driving.

In order to measure visual function using the same conditions as existing measurement equipment, visual targets (Landolt rings, etc.) were displayed without driving operations when measuring dynamic visual acuity (DVA),...
kinetic visual acuity (KVA) and depth perception.

Figure 5(a) indicates the method for measuring DVA. Here, a 0.025-equivalent Landolt ring is moved horizontally across the screen at a fixed visual distance. Angular speed is gradually lowered from an initial rate of 240º/sec (40rpm) and a record made of the fastest speed at which the gap in the Landolt ring can be distinguished. The measurement is repeated five times and the average considered the measured value for DVA.

Figure 5(b) indicates the method for measuring KVA. Here, subjects are asked to distinguish the gap in a Landolt ring as it approaches along the direction of view at a constant speed of 30km/h beginning at a point 50m away and moving to a point 2m away. The earliest distance at which the gap can be distinguished is converted to a measure of visual acuity and used as the KVA value. The Landolt ring is displayed at gradually larger sizes to that its visual acuity value increases proportionally to its distance from the observer’s eye (1.0-equivalent at 30m away, 0.1-equivalent at 3m away). For the measurement system, separate images of Landolt rings approaching from 50m away to 2m away are created for the left eye and for the right eye and the subject presented with both sets of images, taking advantage of binocular disparity to create a three-dimensional image with depth.

Figure 6 indicates the method for measuring depth perception (the three-rod method). One moving rod positioned between two fixed rods (2.5m from the view point) is shifted back and forth 10cm at a time. The moving rod is stopped when the subject indicates that all three rods appear to be aligned the same distance away, and the measure of the displacement between the fixed and movable rods is considered the measured value for depth perception. In driving tests for large-sized vehicle and 2nd-class vehicle licenses, an average result of less than 2cm displacement over three trials is required to pass. For our measurement system, however, in consideration of the variation resulting from three-dimensional display, the average over five trials is used as the measured value for depth perception. Figures 7, 8 and 9 indicate the results for DVA, KVA and depth perception for the same subjects as in the field of view measurements described in
Figure 4. The elderly showed lower DVA, KVA and depth perception than the young, confirming a decline in distance perspective and the ability to discern moving objects.

When measuring static visual acuity, following an eye test under normal lighting, an additional eye test is conducted using a low-contrast visual target to create conditions of low contrast against the background. In addition, a glare source is installed directly above the visual target (at an angle of 4° to the visual target) and an eye test conducted with the light source on to create glare conditions. This measurement of static visual acuity uses the symbol “E” (JISC-standard Snellen chart) displayed with its open side randomly facing one of four directions. Figure 10 indicates the method for measuring static visual acuity, based on test results for the young (15 subjects in their twenties) and the early elderly (22 subjects between 65 and 74). Results show that the elderly have more difficulty than the young in reading visual targets under lower contrast conditions. In addition, results show that elderly people with age-related cataracts have markedly lower visual acuity than the healthy elderly, particularly under glare conditions.

Next, subjects’ performance while driving for 10 minutes on a course (using simulated driving images) including multiple intersections, where accidents involving the elderly frequently occur, is evaluated as a measure of cognitive and decision performance. Unlike most conventional measurement methods that simply measure reaction time and reaction consistency in emergency situations such as when objects jump suddenly into the path of the vehicle, this method measures two indices of driving performance—contact with vehicles or people and intersection passage time—in order to measure the cognitive and decision performance necessary in actual driving situations. Additional explanation of this approach follows below.

Following a review of accident data for the elderly, given the types of accident that occur, divided attention, visuo-spatial cognition and situation assessment are believed to be important aspects of cognitive and decision function. Divided attention is the ability to divide one’s attention among multiple objects, looking after a number of traffic signals, other vehicles, pedestrians, etc. simultaneously or within a short period of time while driving. One expects that the decline in divided attention with age will mean that an increase in the number of objects will bring a corresponding increase in cognitive errors and decision errors. Therefore, in order to include driving situations with varying degrees of divided attention difficulty, three levels of driver workload (low, medium and high) were established with varying numbers of objects to be recognized, as discussed below.

Visuo-spatial cognition is the ability to grasp correctly the positional relationship (distance and relative
speed) between self and other. One expects that the decline in visuo-spatial cognition with age will mean a corresponding increase in the risk of contact with vehicles and pedestrians. Therefore, left-turn situations in which a succession of pedestrians cross the street from both sides and right-turn situations in which a succession of oncoming vehicles approach are included among the driving situations created, and driving performance measured using “contact with vehicles or people” as an index of whether the subject is able to successfully use visuo-spatial cognition to navigate the gaps without coming into contact with pedestrians or oncoming vehicles. As this measure of driving performance also incorporates the decision of how to time passage through successive pedestrians or oncoming vehicles, it is also considered a measure of situational assessment. The “contact with vehicles or pedestrians” index is roughly equivalent to the achievement rate for the task of safe driving. However, because the elderly tend to be cautious while driving, they often take their time and drive slowly, resulting in achievement rates of 100% (no contact). Under the proposed method, subjects are instructed to pass through intersections as quickly as possible, with “intersection passage time” measured as an index. This index measures the time between entering the intersection and completing the left or right turn, and is equivalent to task achievement efficiency.

Figure 11 indicates the method for measuring driving performance at intersections (right turns). Oncoming vehicles initially approach the right-turn intersection with a short headway time (the time interval between the front of one vehicle and that of the next), but headway time gradually increases, making it easier to pass through the intersection. The more accurately the subject can determine the positional relationship and speed of oncoming vehicles, and the quicker subjects can decide to act, the shorter the resulting “intersection passage time,” resulting in driving performance that reflects a measure of cognitive and decision-making speed. However, because there are also pedestrians crossing the street in addition to oncoming vehicles, there is a trade-off with ensuring safe passage by paying attention to multiple objects.

To summarize, the proposed method measures the divided attention, visuo-spatial cognition and situational attention functions believed to be primary causes of the cognitive and decision errors frequently seen in accidents involving the elderly by measuring driving performance using a combination of “contact with vehicles and pedestrians” (equivalent to task achievement rate) and “intersection passage time” (equivalent to task achievement efficiency).

Three levels of difficulty (magnitude of driver workload), as described in Figure 12, are established for intersection passage based on speed and the number of objects (traffic signals, oncoming vehicles, pedestrians) requiring cognition and decision. Furthermore, the three levels of driver workload (low, medium and high) were confirmed to represent three appropriately ordered degrees of workload using NASA-TLX mental workload measurements.

When measuring cognitive and decision function, subjects are instructed to drive safely and obey traffic rules while passing through intersections as quickly as possible. The specific instructions given are as follows:

“When you make right turns at intersections, a succession of oncoming vehicles will approach you. In some cases the oncoming traffic lane is a single lane; in others
it is a double lane. When it is a double lane, oncoming vehicles may appear in both lanes. The speed of oncoming vehicles is faster overall when there are two oncoming lanes than when there is a single oncoming lane, and the speed of the vehicles in each lane may vary. For each lane, the interval between vehicles begins shorter and gradually grows longer. Please pass through the intersection as soon as you determine that you can execute the turn between the oncoming vehicles. Note that there may also be pedestrians crossing the street so rather than paying attention only to oncoming vehicles please take care in passing through the intersection not to force things such that you strike pedestrians when completing the right turn. In other words, avoiding oncoming vehicles and pedestrians is your first priority as you drive through the intersection as quickly as possible."

Driving operations are limited to steering, acceleration and braking; turn signals are not used. Also, because subjects follow the instructions of the experimenter in driving the course, there is no need for them to memorize the course in advance.

Following is an explanation of the measured results for driving performance, looking at the data for both “contact with vehicles and pedestrians” and “intersection passage time.” Subjects had all been driving for at least four weeks and included the young (10 people in their twenties), the middle-aged (8 people in their thirties to fifties), the early elderly (7 people between the ages of 65 and 74) and the late elderly (9 people aged 75 or over).

First, with regard to “contact with vehicles and pedestrians,” only one person among the 18 subjects in the younger age groups (young and middle-aged) struck a pedestrian. Among the 16 subjects in the older age groups (early and late elderly), two struck oncoming vehicles. However, the causes of the contact differed between the younger and older age groups; the younger driver struck a pedestrian due to reckless driving while the older drivers struck oncoming vehicles due to errors in timing the intervals between oncoming vehicles caused by cognitive or decision mistakes.

Figure 13 indicates sample measurements for “intersection passage time” (including only subjects who drove safely through intersections without striking oncoming vehicles or pedestrians), and shows that older drivers take more time to pass through intersections. In addition, a comparison by difficulty of intersection (magnitude of workload) shows that it takes more time to pass through intersections that require a higher workload, suggesting a decline in cognitive and decision function with age. At the same time, elderly drivers are known to be characterized by greater caution and to tend to require more time while driving or passing through intersections than young drivers; here this characteristic is considered part of the cognitive and decision performance of elderly drivers.

The overall time required for testing and measurement is about 30 minutes, including approximately 15 minutes for testing of visual functions (about 5 for static field of view and useful field of view, 4-5 for dynamic and kinetic visual acuity, 2-3 for depth perception, and about 3 for static visual acuity) and about 15 minutes for cognitive and decision function testing. However, in consideration of the burden placed on the elderly, a five-minute break period is established between the testing of visual functions and the testing of cognitive and decision function.

6. SIMPLIFIED MEASUREMENT SYSTEM DESIGNED FOR DRIVING SCHOOLS

In order to make the prototype measurement system available for practical use, a simplified measurement system was developed, intended for use in driving workshops for the elderly at driving schools, that measures two aspects of visual function (field of view and static
visual acuity to address age-related cataracts) as well as cognitive and decision function. Figure 14 shows the exterior of this simplified system. This system is approximately the same size as the driving simulators currently used at driving schools but permits measurement in a relatively short period of time, making testing more convenient and better suited for the elderly. Figure 15 illustrates measurement of both visual function and cognitive and decision function. The system was evaluated using both young and old subjects and confirmed to produce measurements consistent with the measurement system already developed. There are plans for future ease-of-use assessments and trial use at driving schools.

7. CONCLUSION

This paper has described the development of a system to better grasp the driving ability of the growing numbers of elderly drivers (including those who have been diagnosed with dementia) through the comprehensive measurement, under situations approaching actual driving, of the visual, cognitive and decision functions indispensable for recognizing the various objects encountered while driving, as well as the methods for measurement and sample results. Ultimately, the system seeks not only to promote self-awareness of declining driving abilities among the elderly but also to be used in maintaining and improving driving ability through reeducation and training. In the future, additional data for age ranges through the later elderly will be accumulated, issues for practical application identified and further improvements to the system made. In addition, there are also plans to assess not only healthy drivers but also those suspected of dementia in order to consider ways to predict dangerous driving behavior and method for the early detection of dementia.

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