Driving, aging, and temporal factors in vision: an exploratory study

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J.A-A. Smither, M. Mouloua, R.S. Kennedy, M.D.Gentzler. Driving, aging, and temporal factors in vision: an exploratory study. Gerontechnology 2009; 8(3):140-149; doi: 10.4017/gt.2009.08.03.005.00 Task analyses of driving usually list a number of visual activities that require switching perceptions between different visual images. But most tests used for certifying and renewing driver licenses ignore the transient nature of seeing and use visual stimuli presented for extended duration under static conditions. Although considerable literature exists on temporal and spatio-temporal processing, transportable, standardized tests of such abilities have not been generally available. This exploratory study involved using a portable computerized test battery of five temporal-acuity tests that we have developed and administering these tests to participants in three age groups. A computer-based driving game was also administered and time to complete the driving course and the number of lane violations made were recorded. Results suggest that measuring temporal visual factors, in particular backward masking, could yield additional information related to driving performance and age, and that future driving research should include measures of both spatial and temporal visual acuity.

Key words: aging, driving, motion perception, temporal vision

Driving is one of the most complex tasks that people perform on a regular basis[1]. Driving places major demands on human perceptual, cognitive, and motor capabilities and so age-related declines in these capabilities negatively affect driving performance. Given that driving largely involves the processing of visual information that changes rapidly over time, age-related changes in dynamic visual abilities are likely to have some impact on driving performance.

Driving and age-related visual declines

With age, a number of changes occur in the human eye that result in the visual system operating less efficiently[2]. One of the major declines in vision due to aging involves visual acuity[3]. Contrast sensitivity also declines with age[4]. Furthermore, older adults tend to be more affected by glare and have a longer recovery time after having been subjected to it[5].

As perception slows down with age due to limitations in the visual system, perception-response time is negatively affected as well[6]. Older adults conduct visual search less efficiently as compared to younger adults[7]. Older adults also require more light to see than younger adults. Olson and Farber suggested that there is a "substantial decline in nighttime target detection capability as a function of age" and that "a median 70-year-old driver would detect a low-contrast object at about one third the distance as would a median 20-year-old driver"[4]. Being aware of a pedestrian on the dimmer side of the headlight beam (i.e. on the left side of the road in the US) is quite hard and sometimes drivers are unable to do it at all[8]. In order to guarantee that a driver has enough time to avoid hitting a darkly-clad pedestrian, driver speed has to be as low as 15-40 miles (24-64 km) per hour[9-11]. Furthermore, the total visual field usually decreases with age; this reduction in the visual field invariably has serious implications for driving safety since peripheral vision appears to play an important role in crash avoidance, particularly at night[12]. Ball and colleagues used the term useful field of view (UFOV) to describe the visual field area over which information can be acquired in a brief glance without eye or head movement[13]. They went on to develop the UFOV test which has been used extensively over the last twenty years to examine age-related changes in speed of processing and attention. Research indicates that the UFOV test consistently predicts various everyday performance outcomes of older adults including driving outcomes such as at-fault crash involvement[14]. It should be noted, however, that the UFOV test is also a measure of higher order processes (i.e., cognition) and not just lower order processes (i.e., visual perception).

Although research has shown that older adults tend to suffer from declines that impact their driving performance, often times they are aware of these declines and this awareness induces some of them to limit or even stop their driving. McGregor and Chaparro found that most of their older adult participants felt like they needed more time than they had in the past to perform vision-dependent tasks regardless of whether their vision was impaired or not[15]. Furthermore, older drivers who sense changes in their driving abilities drive more slowly, limit their night and highway driving, avoid driving during rush-hour periods, and drive fewer miles[16]. Ruechel and Mann[17] also found that respondents to their structured interviews reported using self-regulation strategies to maintain their driving independence. These older drivers indicated that they based their driving decisions on location, time of day, weather, and types of roads to be travelled. Overall, some older drivers appear to compensate for declines in capabilities through experience and adaptive behaviors, and as such their rate of crashes is probably lower than would be expected.

Temporal factors in vision

In a study where young, middle-aged, and older participants drove on a closed course both during the day and at night, driver performance in terms of speed and recognition of road signs decreased significantly with increased age and reduced illumination[18]. Also, in other research on the effects of aging on night driving, older participants were able to read highway signs at dark at only around two-thirds the distance that the younger participants were able to read the same signs[19].

Concurring with this research, older drivers themselves report having trouble seeing at night, and that includes reading highway signs as well as dashboard instruments[20].

Attempting to read highway signs while driving, adds another dimension to visual performance. This dimension, which is the focus of our research, involves the ability of the eye to discern fine details in a moving target, i.e., temporal factors in vision. One aspect of this dimension (dynamic visual acuity) has been found to be associated with sign-reading performance[21].

The distinction between static and dynamic visual performance extends into physiological differences. Neuroscientific studies of vision have suggested that fine spatial acuity is mediated through the parvocellular division of the lateral geniculate portion of the thalamus[22-24]. These studies also indicated that this pathway subserves the more spatially precise visual capabilities that benefit from sustained inspection of visual information. On the other hand, visual psychophysical functions such as motion, depth perception, and flicker operate much faster and are subserved by a transient visual system. These latter functions appear to be carried by the larger, anatomically distinct, magnocellular division of the geniculo-cortical pathway[23,24].

Not only do separate pathways imply a two-process (or multiple channel) theory of function, but individual behavioral sensitivities found in one division may be uncorrelated with sensitivities found in the other, and both may be involved to a greater or lesser degree in processing many tasks[25]. The important motion processing component of the visual system is critically involved in such temporal domains as visual perception of motion, maintaining smooth pursuit eye movements for visual targets, and extracting moving forms from static backgrounds. Motion perception measures have also been shown to be highly sensitive to stressors such as alcohol and sleep deprivation[26,27], and to individual differences such as age[28-32]. Thus, there is a need to examine systematically the temporal factors involved in perception of motion within the visual system especially as it relates to driving performance. In contrast with traditional measures of visual acuity (for instance, Snellen charts), measures of resolution for moving targets (for instance, visual span, simultaneity, masking, etc.) have shown remarkably stronger relationships with many stimulus and organismic variables and with many applied tasks in which motion perception is involved (for instance, driving, flying, sports, etc.)[26-29,33].

The relationship between measures of resolution for moving targets and driving performance was confirmed in a large study conducted by Burg[33]. In this study, the researchers collected data from almost 18,000 volunteer drivers in California. They collected several measures of visual performance that they then compared to crash and traffic-related conviction records from the Department of Motor Vehicles. The results of this research indicated that dynamic visual acuity had much higher predictive value than any other measure of visual performance, including static acuity, glare recovery, and total lateral visual field[33]. Wood found that the combination of useful field of view, Pelli-Robson letter contrast sensitivity, motion sensitivity, and dynamic acuity predicted 50% of the variance in overall driving scores[34]. Long and Zavod examined dynamic contrast sensitivity as a function of target velocity and revealed especially prominent detrimental effects of increasing target velocity for small targets and brief durations[35]. They suggested that dynamic contrast sensitivity could be a "useful composite measure of visual functioning that may provide a better overall picture of an individual's visual functioning"[35] compared to more traditional measures such as static acuity alone. Such information might allow for improved prediction of performance in visually dynamic situations such as driving.

It is not all that surprising that temporal factors in vision tend to be ignored in driving contexts for older adults, given that a few decades ago they were even ignored for testing visual performance of military and commercial pilots despite research recommending they be assessed in those extreme contexts[32]. Given the importance of temporal factors for driving and their age-related declines, it would make sense to have tests of this visual function to identify at-risk drivers. However, temporal factors in vision are not tested in certification and renewal of driver licenses or in testing for other visually demanding tasks. Since transportable and standardized tests of these dynamic visual abilities have not been generally available for use in clinical, commercial, military or other applications, we developed a battery of computer-based tests that characterize the motion perception capabilities of an individual. As a first approximation of a driving simulator, a commercial off-the-shelf computer driving game was also administered.

Methods

Temporal factors battery

The temporal acuity battery that we used[36] contains a series of five tests implemented on an IBM-compatible 40 MHz 386DX personal computer (PC) with 1M RAM and 14-inch SVGA monitor. The five temporal acuity tests are named: (i) Visual span; (ii) Simultaneity; (iii) Phi phenomenon; (iv) Bistable stroboscopic motion and; (v) Backward masking. For several of the tests, a procedure called the Parameter Estimation by Sequential Testing (PEST) was programmed on the computer to rapidly determine the 'threshold' for the psychometric function[37]. The threshold is defined by the observer's response probability as a function of an independent, physical variable. This information is collected by means of a staircase-like method in which each time a measurement is to be taken, all of the previous measurements can be used to obtain a maximum likelihood estimate of the independent variable that will yield the most information regarding the observer's threshold. Each test required approximately three minutes to complete. Furthermore, all stimuli presented in the tests were straight-up with no tilt. A description of the tests follows.

Visual span

Visual span measures the ability to capture two objects in one saccade as the objects alternate. In this task, a square C opening to the right or opening to the left (a backwards C) was presented on the left side of the screen and then on the right side. Sometimes the two Cs both faced forward, and sometimes one would face forward and the other backward. The participant's task was to determine whether the opening of the C on the left and right sides of the screen had the same or different orientation. The participant was given four seconds to make the determination. Each square C occupied an area of 0.56 cm^2 (0.75 cm per side). Furthermore, the two Cs subtended a visual angle of 20.6^o. The presentation of the two Cs was separated by a variable interstimulus interval (ISI). A PEST procedure was used to determine the threshold ISI for making the judgment where a correct response decreases the ISI, and an incorrect response increases the ISI. The ISI of the fifth reversal is recorded. A low ISI signifies good temporal acuity.

Simultaneity

Simultaneity refers to one's ability to recognize whether two visual stimuli are presented simultaneously or whether they are temporally separate. In this task, as the participant stares at a fixation point in the middle of the screen, two square open boxes (0.75 cm per side) subtending a visual angle of 12.18^o are alternately flashed on the screen to the left and right of fixation for 60 msec. One of the two boxes, the left or the right, preceded the other at random. The presentation of the two boxes was separated by a variable interstimulus interval (ISI). The participant was required to report which box, the left or the right, appears first. A PEST procedure was used to determine the threshold ISI for making the judgment where a correct response decreases the ISI, and an incorrect response increases the ISI. The ISI of the fifth reversal was recorded. A low ISI signifies low persistence and good temporal acuity.

Phi phenomenon

Apparent motion is the illusion of continuous movement resulting from the momentary presentation of an object at an orderly set of locations in the visual field[38]. To elicit perceptions of apparent motion, the participant was presented with two square boxes (0.75 cm per side) 33 mm apart on the computer screen. When viewed at a comfortable distance (0.4 m) the objects were about two degrees to the left and right of fixation. The participant was provided with a set of response keys in order to adjust the ISI to the point where the objects did not appear successive, but appeared perceptually to move back and forth. The PEST procedure was used for determining the point on each trial where a participant reported the change from succession to movement and back again. The procedure was repeated until five reversals occurred and the value at that point was the participant's score. A low ISI value signifies good temporal acuity.

Stroboscopic motion
In this task[38] an array of stimuli (square boxes with 0.75 cm per side) were alternately cycled. Time frame 1 consisted of three horizontal elements of boxes with equal center-to-center distances. Time frame 2 had identical elements shifted to the right by a distance equal to the center-to-center separation between stimuli. Participants were required to report whether they perceived the end two boxes flickering on and off (element motion), or a group of three squares moving together in a left-right direction (group motion). The PEST procedure was used to determine thresholds for group motion; on each trial that the participant reported element motion the ISI was increased, and on each trial that the participant reported group motion, the ISI was decreased. The procedure was repeated until five ISI reversals (transition from one type of motion to the other) occurred. The ISI of the last reversal was recorded. A low ISI signifies low persistence and good temporal acuity.

Temporal masking
In temporal masking, the participant was presented with two stimuli in quick succession. The first stimulus was a figure consisting of two vertical lines, close together (0.75 cm apart), 0.75 degrees of visual angle in length and .05 degrees wide. A horizontal line 0.05 degrees in length extended from the midpoint of either the left or right vertical line. After a brief period, the lines were replaced by a complex pattern (the mask). The screen went blank and the participant was instructed to press either the left or right arrow keys depending upon whether the horizontal line was on the left or right vertical line. A brief tone signaled the start of each trial. A low ISI signifies good temporal acuity.

It should be noted that the temporal acuity tests described above were set up so that they did not measure response latency per se so as not to confound reaction time measures with visual performance. This was done because it is well established that older adults' reaction times are generally slower than those of younger adults. Instead, the tests presented stimuli at different speeds and durations and so participant hits or misses were recorded.

Participants
Thirty participants were recruited for this study. The volunteers came from three age groups: 18-35 (27.3±5.0); 40-55 (47.2±3.65); and 60-80 (72.5±4.0) years. The young group was recruited from classes at the local university, the middle aged group was recruited from the support staff at the university, and the older group was recruited from an older adult organization that was affiliated with the university and met there for weekly lectures. Each group included five male and five female participants. Participants had at least 20/40 corrected vision as measured by an OPTEC vision tester. All participants currently drove. Participants were advised about the purposes and procedures of the experiment, and informed consent was obtained.

Apparatus and tasks
Participants were administered the temporal factors battery and the driving simulator game (see above). To provide a first approximation of a driving simulator, 'Need 4 Speed 2', was used. The game ran on a PC and was displayed on a 14″ SVGA monitor. Participants were instructed to keep their car in their lane on the simulated highway. The number of lane violations and time to completion were recorded.

Procedure
Participants' temporal visual acuity was assessed in two sessions over two days. The temporal factors battery was administered twice during session 1 and once during session 2. The five sub-tests of the temporal

factors test battery were always presented in the same order: visual span, simultaneity, Phi phenomenon, bistable stroboscopic motion, and backward masking. This computerized test battery was self-administered and automatically scored. It should be noted here that built into the beginning of each test were a specific number of trials that served as practice and were not considered in the data analyses. The number of trials necessary to mitigate possible learning effects was empirically determined during the battery development phase. After the administration of the temporal factors battery in the second session, participants completed the PC-based driving simulation task twice.

Results

The scores for the five temporal factors tests (visual span, simultaneity, phi, strobe, and masking) were each averaged over the three administrations. Because the first driving simulation task was considered a practice session, the lane violation score and the car-session time score used in the analyses were those obtained from the second driving simulation task. Prior to analyzing the data, all variables of interest were checked for distribution normality. Several of the variables had significant outliers, including simultaneity, phi, strobe, and masking. In addition to these tests, the variables of age (as a continuous variable) and the dependent measures (lane violations and car-session time) had some noticeable departure from normality. Therefore we took the natural log of all the variables of interest and obtained more normal distributions. All subsequent analyses were performed using the natural log data.

Intercorrelations

As was expected, age was significantly related to a number of measures, including visual span, simultaneity, masking, number of lane violations, and time to complete the course (*Table 1*). In addition to correlating with age, lane violations significantly correlated with visual span and masking, and time to complete the course significantly correlated with simultaneity.

Age-group effects

A multivariate analysis of variance (MANOVA) of the effect of age group was conducted on the data. Dependent variables included performance on the temporal factors battery, number of lane violations committed, and time to complete the driving course. The analysis indicated significant differences between the groups using Pillai's Trace ($F(14,40)=5.45$, $p<0.001$). The univariate tests of between subjects' effects indicated several significant effects:

Table 1. Inter-correlation matrix (Pearson) between performance measures, temporal factors, and age; Natural logarithms are taken from the measurement; 2-tailed testing of significance; italic= p<0.05; bold=p<0.01

	Correlations (n)						
	Visual span	Simultaneity	Phi phenomenon	Bistable stroboscopic motion	Backward masking	Age	Lane violation
Simultaneity	**0.505** (30)	1.000 (30)					
Phi phenomenon	0.141 (30)	0.167 (30)	1.000 (30)				
Bistable stroboscopic motion	-0.012 (30)	0.073 (30)	0.289 (30)	1.000 (30)			
Backward masking	**0.663** (30)	**0.635** (30)	0.276 (30)	0.089 (30)	1.000 (30)		
Age	**0.473** (30)	**0.515** (30)	0.234 (30)	-0.280 (30)	**0.704** (30)	1.000 (30)	
Lane violation	**0.486** (28)	0.346 (28)	0.321 (28)	-0.007 (28)	**0.546** (28)	**0.519** (28)	1.000 (28)
Completion time	0.176 (28)	*0.396* (28)	-0.158 (28)	-0.137 (28)	0.153 (28)	*0.452* (28)	0.065 (28)

Temporal factors battery
The ANOVA on the temporal factors battery indicated significant effects of age group on visual span, ($F(2,25)=8.66$, $p=0.001$). Older participants performed less well than both young and middle age participants who were not different from each other. The analysis also indicated a significant effect of age group on simultaneity, $F(2,25)=5.93$, $p=0.008$. Older participants performed less well than the young ones. Finally, the analysis indicated a significant effect of age group on masking performance, $F(2,25)=14.17$, $p<0.001$. Older participants performed less well on the masking task than both young and middle-age participants who were not different from each other.

Driving simulation: violations
The ANOVA on the number of violations (for instance, lane departures) in the driving game indicated a significant effect of age group on performance, $F(2,25)=5.45$, $p=0.011$. Older participants, on average, committed significantly more lane violations than younger ones.

Driving simulation: navigation
The ANOVA on the time to navigate the driving game course indicated a significant effect of age group on performance, $F(2,25)=4.62$, $p=0.020$. Older participants took longer to navigate the course than younger ones.

Regression analyses
In addition to the bivariate correlational analysis and the comparisons by age group described above, two stepwise multiple regression analyses were conducted on the number of lane violations and the time to complete the course, with age and the five temporal factors tests included as the predictors. The analyses showed that: (i) Masking was a significant predictor of the number of lane violations ($F(1,27)=12.12$, $p=0.002$, $R^2=0.318$, $Y=0.129+0.773*Masking$). Participants who were better at masking had fewer lane violations on this task; and, (ii) Age was a significant predictor of the time to complete the course ($F(1,27)=6.69$, $p=0.016$, $R^2=0.205$, $Y=0.165+0.627*Age$). Participants who were younger completed the course in a shorter time.

Although the literature contains a large number of studies investigating the relationship of visual performance and driving with smaller sample sizes, we adjusted our data for normality and found that it did not deviate from the assumptions needed for the statistical tests we conducted. We therefore believe that our findings provide a valid basis for future research with larger sample sizes.

Discussion
Although extensive research underlies the development of tests for static spatial acuity, temporal factors in vision have not received significant study. As a result, the effect of these factors on performance is largely unknown. This may be because, while a considerable literature exists on temporal and spatio-temporal processing, standardized tests of temporal abilities are not available for use in laboratory, commercial or military settings.

Over the last decade, however, we developed and evaluated a battery of computer-administered tests that characterize the temporal processing capabilities of individuals. Our research has resulted in the development of a test battery that has satisfactory statistical properties, i.e., reliability, factor richness, sensitivity, and predictive validity. This temporal factors battery has been validated with the PILOT shuttle landing training program at NASA[40]. It has also been validated as a surrogate task for declines in performance associated with alcohol consumption[41].

The premise of the research is that individuals possess different amounts of temporal acuity, which is defined as the minimum latency between visual stimuli before they are seen as separate, and that these amounts are stable and reliable. In addition, these abilities do not overlap with traditional cognitive or spatial visual abilities, and individuals with greater temporal acuity outperform those with lesser.

Results of this research indicate that three of the temporal factors in vision we tested (visual span, simultaneity and masking) correlate with age. Younger participants in our study had better temporal acuity than older ones. We also found age-related effects on the surrogate driving task. Both the number of violations committed by the participants and the time required to navigate a course were significantly related to age. It is interesting to note that although older adults took longer to complete the course, they still had more lane violations than younger and middle-aged adults. As such, older adults' performance may not be explained by a speed/accuracy trade off. Furthermore, these results constitute a replication of the results by Perryman and Fitten who also found that older drivers, on average, committed more lane deviations and drove more slowly than younger participants[42]. The similarity of results from this driving game and the study of real-world driving by Perryman and Fitten provide some evidence of convergent validity and suggest that the driving game employed has some generalizability to real driving tasks.

In addition to age-related effects, performance on components of the temporal factors battery correlated with performance on the driving task. Masking performance was a significant predictor of maintaining lane position. Regardless of age, participants who were 'better' at masking had fewer lane violations. Higher performance on the masking test may indicate that an individual has a more sensitive visual temporal system. As such that individual has the ability to recognize a potential lane departure early because he or she is less likely to have the line between the lanes temporarily blurred (i.e. masked) by another visual stimulus on the road. Although this finding is quite interesting, it should be noted that it is correlational and does not imply causality, thus it warrants further research.

Although this study is of an exploratory nature because of the small number of participants and the limited driving simulation task, the results support our contention that measuring temporal visual factors could yield additional information related to driving performance. The findings suggest that future research is needed to identify the impact these factors may have and to determine whether declines in them can be mediated by experience and/or adaptive behavior. Future research with older adults of varying temporal factors abilities may help enhance aging researchers' understanding of factors that could be used to identify at-risk older drivers. Assessment of motion perception may also be necessary when investigating cognitive factors like attention because performance on lower order processes such as motion detection undoubtedly impacts higher order functioning. Lower order processes can therefore be a potential source of confounding. Simply put, you have to see a stimulus before you can pay attention to it. For these reasons, we believe that future driving research should always include measures of both spatial and temporal visual acuity.

Although the current research focused on the five temporal factors in our battery, other aspects of motion perception such as movement-in-depth (LOOM) and Dynamic Visual Acuity (DVA) are also related to driving performance[29,43]. Studies that include measures of both spatial and temporal visual acuity may lead to the formulation of a model of performance that can be used to decompose the various visual perception functions in driving and their relationship to aging. The need for such a model was stated by Higgins when he wrote, "to date, no convincing empirical evidence has shown that the increased risk of accident involvement in the elderly is due to losses in vision per se" [44]. We believe that by developing and testing a practical temporal factors battery, we have responded to his urging that "new experimental approaches are needed…" in the areas of driver vision testing and licensure.

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