Sign Detection and Driving Competency for Older Drivers with Impaired Vision

Janine G Walker[1], Nick Barnes[2,3] and Kaarin Anstey1
1. Centre for Mental Health Research, The Australian National University
2. National ICT Australia, Locked Bag 8001, Canberra, ACT 2601
3. Department Of Information Engineering, The Australian National University
janine.walker@anu.edu.au, nick.barnes@nicta.com.au

Abstract

Driving is a key aspect of independence for many older individuals. However, road safety may be compromised if an individual is not able to perceive adequately the driving environment. In this paper, we examine whether driver assistance systems that are currently the subject of research can help in this regard. Specifically, can we identify deficits that lead to older adults needing to cease driving, and can technologies reduce the impact of these deficits on driver competence. Results from a study of older adults with cataract who are awaiting surgery showed that impaired visual acuity was associated with difficulties reading road signs. In a significant proportion of the group studied, reading signs was their major issue in driving. We summarise some sign detection results from the NICTA/ANU Intelligent Vehicle Project and review other current literature on sign detection and recognition, and evaluate the potential of this line of research for assisting older adults' driving competence and road safety.

1 Introduction

In order to facilitate older individuals driving safely, further research is needed that examines specific difficulties they experience with driving, in conjunction with multidisciplinary and novel approaches to tackling these issues. This paper addresses whether current engineering and robotics research into driver assistance has the potential to enhance driver competency for older adults. Naturally, technologies developed may assist drivers generally; however, in this paper we show a significant group of the population have a functional impairment that may be overcome directly by a robotic assistive device for a particular context.

Individuals aged 65 years and over represent the most rapidly growing segment of the driving population, and are keeping their licenses longer [Lyman *et al.*, 2002]. One of the benefits afforded to individuals by driving is maintaining mobility and independence which are important components of quality of life. Ensuring that older people maintain independence and mobility for as long as possible may reduce burden on health care and community resources. Driving capability is linked to other domains of functioning [Gilhotra *et al.*, 2001; Marottoli *et al.*, 2000; Marshall *et al.*, 2002]. Indeed, individuals who have reduced or ceased driving may be at increased risk of isolation, poor mental health, and associated functional impairment and cognitive decline [Fonda *et al.*, 2001].

However, there needs to be a balance between maintaining older people's quality of life, including the ability to drive, and addressing issues of driver competency and road safety. It should be acknowledged that motor vehicle crash rates adjusted for miles driven are higher for elderly drivers, with an exponential increase above the age of 75 [Preusser *et al.*, 1998]; a similar pattern is observed for driver fatality rates. As well as the obvious health, injury, and potential disability consequences for the older drivers involved in a motor vehicle accident, there is a financial burden placed on the community [Miller *et al.*, 1998].

Many older drivers face impaired visual functioning; cataract and related visual impairment is highly prevalent [Rochtchina *et al.*, 2003]. In 2001, 1.7 million Australians had clinically significant cataract in either eye [Rochtchina *et al.*, 2003]; this number will grow, reflecting population ageing [Ivers *et al.*, 2000]. Cross-sectional and longitudinal studies have demonstrated adequate vision or visual impairment are important factors for everyday physical functioning, driving, and independence in older adults [Owsley *et al.*, 1999; 2002; West *et al.*, 2002]. However, little is known about the relationship between vision impairment, as measured by clinical tests such as visual acuity, and resulting difficulties with driving behaviours [Haymes *et al.*, 2002].

Associations between cataract and crash involvement have also been reported. In a case-control study, it was found that drivers with cataract were 2.5 times more likely to be involved in a crash than drivers without cataract [Owsley *et al.*, 1999; 2002]. Patients who had cataract surgery had half the crash rate during the follow-up period compared with those who did not have surgery [Owsley *et al.*, 2001].

In this paper, we examine visual impairment associated with cataract, and its impact on self-reported driving behaviours. The results indicate that poor visual acuity is associated with difficulties in reading road signs. In turn, reduced ability to read signs is significantly associated with vision-related driving difficulty. Given this finding, we explore whether current research in sign recognition may assist driver competency and safety. Further, sign reading technologies could assist older individuals in other ways, such as when they are pedestrians; however, the driving context is a good starting point as it is better defined and constrained. Further, when incorporated within a vehicle, devices need not be obtrusive, but included in the standard interface.

Subsequently, we review the literature on sign detection and recognition, and summarise some relevant results from the ANU/NICTA Intelligent Vehicle Project. We evaluate whether this line of research has the potential to enhance driver competence for older adults with visual impairment.

2 Older driver study

In this section, we present results from a randomised controlled trial for cataract surgery in older adults. The study considered patients on a waiting list for cataract surgery. Among other variables, the study examined difficulties that the participants had regarding driving behaviours.

2.1 Methods

Participants: The sample comprised 105 participants (44 men, 61 women) requiring cataract surgery who were recruited from outpatient ophthalmology clinics in three teaching hospitals in Sydney, Australia. Cases were restricted to mostly posterior subcapsular opacities to reduce the measurement variability of corrected visual acuity from refractive changes often seen with nuclear cataract. For inclusion, participants had to have preoperative visual acuity in the better eye of 6/24 to 6/36. The minimum inclusion age was 55 years with no specified maximum age. The exclusion criteria were: a neurological condition; impaired cognition; another eye disease; and, hearing impairment.

Design and procedures: Participating hospitals, as well as the University of New South Wales were granted human research ethics approval. After obtaining informed consent, a home-based assessment included measures of visual acuity, and cognitive tasks in both visual and auditory modalities. Participants completed self-report surveys, including: demographic information; health status, health care and medication use, number of comorbid conditions; psychosocial functioning; and, vision-related disability.

Measures of vision: Visual acuity was assessed using a logMAR (log of minutes of arc) transparency on an illuminated light box. Alphabetical characters on the transparency varied in size by 0.1 logMAR units between rows, which patients read at a testing distance of 3 m [Haymes *et al.*, 2002]. The smallest visual angle, i.e., the smallest line read with one or no errors, was recorded.

The Melbourne Edge Test (MET) assessed edge contrast sensitivity at 25 cm. with a background luminance of 50 Cd m- 2 [Haymes *et al.*, 2002]. The MET measures the contrast threshold for a single luminance profile edge, which is an aperiodic stimulus, by presenting 20 circular patches containing edges with reducing contrast and variable orientation. Contrast sensitivity is measured in decibel units. The MET has excellent test properties [Verbaken and Johnston, 1986]. This means that it has been widely used over a range of populations including clinical studies on older adults and subjects with cataract, has good test-retest reliability, and is able to detect change scores.

Measure of visual disability and vision-related driving ability

Vision-related disability and vision-related driving ability was measured using the Visual Functioning - 14 (VF-14) [Steinberg *et al.*, 1994]. The VF-14 is a brief self-report questionnaire designed to measure functional impairment caused by cataract, and has been used with other ocular disorders [Alonso *et al.*, 1997; Pager, 2004]. The VF-14 consists of 14 items rated on a five-point Likert scale (0 = cannot do activity to 4 = have no difficulty with activity) that assess difficulty experienced on vision-related activities, such as reading a newspaper, watching television, and taking part in sports. Also, the VF-14 comprises four driving-related items, including:

Do you have difficulty, even with eyeglasses -

1. reading road signs;
2. seeing curbs;
3. driving during the day because of your vision;
4. driving at night because of your vision.[1]

[1] In this paper, we examined only daytime driving and reading road signs. Note that older drivers tend to avoid driving in adverse conditions. However, the detection technologies described here have been demonstrated to operate well at night-time and in rain.

Responses were weighted to give scores between 0 and 100 with a lower score indicating greater vision-related disability. The VF-14 has excellent validity and internal consistency for cataract patient samples (α=.85) [Steinberg *et al.*, 1994; Cassard *et al.*, 1995].

Characteristics	Number	Percent
Age, years	mean=73.69	SD=7.10
Sex		
Male	44	41.90
Female	61	58.10
Education, years	mean=9.76	SD=2.81
9 years	63	60.00
10 - 13 years	31	29.60
14 years	11	10.60
Marital status		
Married / de facto	60	57.10
Single	7	6.70
Divorced / separated	9	8.60
Widowed	29	27.60
First language		
English	93	88.60
Southern European	4	3.90
Northern European	7	6.70
Arabic	1	1.00

Table 1: Demographic characteristics of 105 participants with cataract, shown as raw number and percentage (except age and education that are noted to be mean and standard deviation).

Statistical analyses: SPSS v.12.0 was used for statistical analyses. Stepwise hierarchical multiple regression analyses determined whether demographic, health status, and visual functioning were associated with driving-related behaviours including driving and ability to read road signs. Four blocks of variables were entered into the analysis for driving, including: 1) demographic - age and sex; 2) health status - number of comorbid conditions, medication use, and number of GP visits in the last year; 3) visual functioning - MET, and logMAR scores for better and worse eye; and, 4) ability to read road signs. For reading road signs, three blocks of variables were entered into the analysis, including: 1) demographic; 2) health status; and, 3) visual functioning. Analysis of variance (ANOVA) was used to determine if there were any significant differences between drivers and non-drivers on demographic, health status, visual functioning, and vision-related disability variables.

Characteristics	Mean	SD
Health status		
Health rating	4.54	1.38
# prescription medications	3.86	2.99
# GP visits previous year	11.84	12.33
# comorbid conditions	2.77	1.92
Visual acuity		
LogMAR better eye	2.14	1.26
LogMAR worse eye	3.80	2.06
Melbourne Edge Test	19.48	2.86
Total VF-14 Index	78.75	15.91

Table 2: Clinical characteristics of 105 participants with cataract

2.2 Results

Participant characteristics: Participants' ages ranged from 58 to 91 years (mean age = 73.69 years; SD = 7.10), and 58.1% were women. The majority of participants was married (57.1%), spoke English at home (88.6%), and had not completed secondary education (74.3%; Table 1). Most participants rated their health as better than average (57.1%) despite the fact that 74.3% had multiple comorbid health conditions, and the mean number of GP visits during the past year was 11.84 (*SD* = 12.36; Table 2). For visual acuity, the mean logMAR for the better eye was 2.52 (*SD* = 1.36), and the mean MET score was 19.48 (*SD* = 2.86). As well, participants had difficulty with vision-related functioning (*M* = 78.75, *SD* = 15.91, range = 28.85 - 100), which is similar to previous cataract studies [Steinberg *et al.*, 1994; Friedman *et al.*, 2002].

Comparison between drivers and nondrivers: ANOVA was conducted to determine if there were any differences on a range of demographic, health status, visual functioning and vision-related disability between current drivers and nondrivers. Drivers tended to be younger [$F(1, 103) = 7.99$, $p = .006$], male [$F(1, 103) = 9.08$, $p = .003$], and had better self-reported health status than nondrivers as indicated by fewer comorbid health conditions [$F(1, 103) = 6.18$, $p = .014$], and use of fewer medications [$F(1, 103) = 5.81$, $p = .018$]. Current drivers also had better visual functioning with greater visual acuity in the better eye [$F(1, 103) = 6.28$, $p = .014$] than nondrivers (Table 3).

Difficulties driving and reading road signs: Many older drivers with cataract had difficulties (n = 49) with driving, and problems with being able to read road signs. Forty-five percent of drivers had difficulty driving because of their vision, and half of those had a moderate to great deal of difficulty driving. Further, 37% of drivers had difficulty reading road signs with most of these individuals (77%) reporting moderate to high levels of difficulty.

Correlates of vision-related functioning: Multiple regression analyses indicated that age and difficulty reading road signs accounted for 38.90% of the variance for driving [$\beta = .56$, $F(2,47) = 14.64$, $p < .0001$] reading

	Characteristics	Drivers Mean	Drivers SD	Nondrivers Mean	Nondrivers SD
Demographics	Age	71.51	6.09	75.30	7.61*
	Sex	57.14% men		76.79% women*	
	Partnered	73.47%		48.21%	
Health status	# prescription medications	3.00	2.48	4.34	3.21*
	# GP visits in last year	11.92	12.70	11.23	11.74
	# comorbid conditions	2.29	1.53	3.163	2.06*
Visual acuity	LogMAR better eye	2.41	1.35	2.14	1.25*
	LogMAR worse eye	3.61	2.05	3.93	2.05
	Melbourne Edge Test	19.90	2.67	19.18	2.89
	Reading road signs	3.24	1.11	3.13	1.05
	Total VF-14 Index	80.34	16.97	76.76	15.07

Note. * indicates that $p < .05$ meaning that the hypothesis that there are no differences between drivers and nondrivers can be rejected.

Table 3: Comparison between drivers (n = 49) and nondrivers (n = 56) on demographic, health status, visual functioning and vision-related disability variables.

signs, accounting for 30% of the unique variance (Table 4). Visual acuity, specifically worse eye logMAR, was associated with difficulties with reading road signs accounting for 12.0% of the variance [β= -.35, $F(2,47)$ = 6.42, $p < .015$].

2.3 Discussion

The present study had three principle aims in relation to driving for older individuals with cataract including to determine whether: 1) there are any differences between current drivers and nondrivers; 2) drivers report difficulties with ability to read road signs; and, 3) demographic, health, visual functioning are associated with difficulties with driving and ability to read road signs.

Older drivers and nondrivers were significantly different on a range of variables. For instance, nondrivers tended to be older, were mostly women, had poorer health, and had worse visual acuity than current drivers. Individuals with chronic health conditions consistently indicate that of all the limitations they may face as a consequence of a medical condition or poor vision, difficulties with driving and mobility, as well as recreational and social activities are of greatest concern [Katz and Yelin, 2001; Verbrugge, 1990; Anstey *et al.*, 2005; Dellinger *et al.*, 2001]. As a valued activity, driving cessation can lead to marked levels of distress when due to poor vision and health [Rovner and Casten, 2002].

Many of the current drivers had difficulties with driving and problems with being able to read traffic signs. Visual acuity in the worse eye was the variable most associated with difficulties reading road signs ($P = .015$). Further, difficulty reading road signs ($P = .001$) and being older ($P = .035$) were associated with difficulties with driving, accounting for 30% and 9% of the variance, respectively. Previous studies have shown that poor visual acuity may be associated with reduced driving, driving cessation, and greater involvement in motor vehicle accidents [Owsley *et al.*, 2002; 2001; Friedman *et al.*, 2002]. The ability to accurately judge distances and perceive spatial relationships is important for many activities of daily living, including reading traffic signs and driving; good vision in both eyes is necessary for these tasks [Lord and Dayhew, 2001].

There are limitations to this study that must be considered when interpreting the findings. Firstly, the study lacks a control group free from ocular disease; however, this was rectified by comparing scores with age-matched norms. Despite our recruitment method of contacting all patients on waiting lists from three sites, and ensuring that the samples education level was similar to other population-based studies of older Australian adults, individuals who participated may differ from non-participants in terms of physical and mental health or daytime commitments. The cross-sectional nature of the data also precludes analysis of potential dynamic interrelationships amongst the key measures; and limits conclusions regarding cause and effect relationships.

3 Study Conclusions

Difficulties reading traffic signs and visual acuity are important influences on driver competency and safety for older people with ocular conditions. This finding indicates that technologies that can enhance older individuals ability to read traffic signs may be a useful way to support and improve driver competency and safety, and delay driving cessation. Automated sign detection and recognition may prolong a visually impaired older person's ability to continue driving, and as a consequence maintain their quality of life, mobility, independence and

	Variable	Daytime driving			Reading road signs		
		β	R^2 change	P	β	R^2 change	P
Step 1	Age	**.193**		.035	.138		.324
	Sex	-.094	.09	.515	-.217		.118
Step 2	Drug	-.003		.984	-.137		.332
	GP	-.137		.349	-.024		.866
	Com	-.115		.415	-.182		.189
Step 3	B log	.071		.623	-.046		.764
	W log	-.234		.097	**-.347**		.015
	MET	.223		.110	.192	.12	.166
Step 4	Signs	**.557**	.299	.001		N/A	

Note. Drug = Number of prescription medications taken, GP = Number of GP visits in last year, Com = Number of comorbid conditions, B log = Better eye logMAR score, Wlog = Worse eye logMAR score, MET = Melbourne Edge Test.

Table 4: Hierarchical regression analyses for reading road signs and driving for 49 current drivers with cataract.

Figure 1: Inside the ANU/NICTA intelligent vehicle. Cameras to monitor the road scene appear in place of the rear-vision mirror.

overall well-being. From a community perspective, these technologies also improve road safety for all road users.

The results indicate that of all potential vision-related risk factors for driving competency and safety, visual acuity and difficulty with detecting signs are possibly the most important. Specifically, the results indicate that these were significantly more important than seeing the edges of the road, which is an example of a major structural element of the driving scene. We can then presume that assisting in sign detection may improve overall driving safety as other basic aspects of driving related to vision were not rated as presenting the same level of difficulty.

4 Automated sign detection and recognition

Research in sign detection and recognition is now at the stage where commercial systems are likely in coming years. Recent approaches often use separate stages of sign detection and classification of sign type (e.g., [Paclik *et al.*, 2000; Miura *et al.*, 2000; Priese *et al.*, 1994]). As classification techniques typically have a high computational cost per pixel processed, detection aims to identify all possible signs in the input stream, but leave only a small fraction of the stream to be examined by classification. Even for a small number of sign types, many classification methods are too slow to be applied to the whole image. A computationally efficient detection stage facilitates a reduction in computationally intensive classification, without requiring assumptions about where signs may appear.

In terms of sign recognition, [Piccioli *et al.*, 1996] report correct classification rate percentages in the high 90's. Although this is inadequate for a commercial system in driving (where results of around 100% are expected), it suggests that with possible incorporation of additional cues, and further research, a commercial system is possible in the near future. For example, we applied superresolution over multiple images to improve classifier reliability [Fletcher *et al.*, 2005].

Some researchers have suggested input stream reduction by using *a priori* assumptions about image formation. At its simplest, one can assume that the road is approximately straight, so large portions of the image can be ignored as signs will not appear in them. Others combine with colour segmentation [Hsu and Huang, 2001] to look for signs in only a restricted part of the image. However, such assumptions can break down on curved roads, or non-planar roads. A more sophisticated approach is to use some form of detection to facilitate scene understanding, and thus eliminate large image regions. For example, Piccoli *et. al* [Piccioli *et al.*, 1996] suggest that large uniform regions of the image correspond to the road and sky, and thus it is only necessary to look in the region alongside the road and below the sky where signs are likely to appear. However, signs can appear on both sides of the road, or even overhead, and under trees. The sky can be broken up by tree branches, or by buildings in city areas, and the road surface broken up by their shadows. Although some *a priori* assumptions may be reasonable for a significant fraction of road scenes, this is not adequate when the system must aim for close to 100% reliability.

5 Suitability of current sign detection/recognition research for supporting older drivers

In the NICTA/ANU Intelligent Vehicle Project, our work on detection of round [Barnes and Zelinsky, 2004] and regular polygonal signs [Barnes *et al.*, 2005; Barnes and Loy, 2005] has reported real time results for detection, facilitating real-time detection and recognition of critical signs. We refer to signs such as stop, giveway, roundabout, and speed signs as critical signs, that is, they require a timely action by the driver. In order to support older drivers, a sign recognition system needs to compensate for difficulties reading signs. In the case of critical signs, this must be early notification of signs detected so that the driver can respond in a timely manner.

The regular polygon algorithm is a real-time, scan-line algorithm that detects regular polygons through a vote-style algorithm. Regular polygons are any closed shape that has three or more sides, where the angle between each side is equal. Triangles, squares (and diamonds), and octagons are examples. The degenerate case of the regular polygon is a circle (a regular polygon with an infinite number of sides). The radial symmetry algorithm can handle such a case with an algorithm that is also real-time and scan-line [Loy and Zelinsky, 2003].

The algorithm works by firstly computing an image gradient vector field, all elements with magnitudes under a predefined threshold are set to zero. For each radius under consideration a vote image is computed of the same size as the input image. Each non-zero element of the gradient field is considered, and possible shape centroid locations given an edge pixel at this location with the specified orientation are computed. This corresponds to a line, twice the length of any side of a sign for the given radius, at a radius distance away from the gradient element in the normal direction of the gradient. The gradient element 'votes' for each of these possible centroid locations. Once every gradient element in the image has voted, the centroids of the sought regular polygons will accumulate many votes, while points that are not the centroids of regular polygons will accumulate fewer votes.

We have implemented the regular polygon detector, and the radial symmetry algorithm to run at greater than 20 frames per second on a standard PC for 320x240 sized images. Figure 2 shows images of a roundabout and speed sign taken from the vehicle (see Figure 1), and their corresponding detection images. We require that a sign candidate is present for multiple images before it is subject to classification. During this time its position may only move slightly per frame, and can only increment by one in its detected radius. In this way, we are able to only have a few false positives per frame, and are generally able to recognise a sign for many frames while it is in the field of view of the camera. In tests conducted to this stage, the radial symmetry algorithm has fewer false positives, similar detection results, also with real-time performance [Barnes and Loy, 2005]. This algorithm has also been generalised to efficiently process multiple regular polygon shape classes [Barnes *et al.*, 2005]. For speed signs, over a limited set of data, we have found correct detections can be around 0.8196 per frame with a low enough set of false positives per frame as to be processed real-time by classification, given that the sign must be present for two frames. Given signs are generally visible for many frames at 30Hz, this equates to a low number of signs missed.

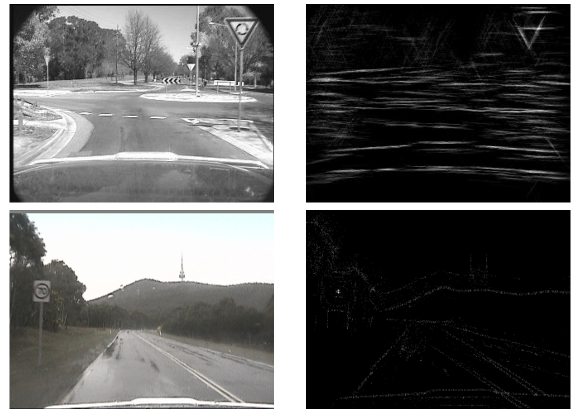

Figure 2: (a) A roundabout sign, and (c) A speed sign on a rainy day, taken from sequences from the ANU/NICTA intelligent vehicle. (b) Regular polygon detection image. The peak is at the intersection of the three projected sign edges. (d) The radial symmetry detection image. A clear single peak corresponds to the sign.

Once a sign candidate is found, we evaluated the effectiveness of combination with standard classification methods by combining either detector with normalised cross correlation [Barnes and Zelinsky, 2004]. For each candidate found, we were able to run the cross correlation on only a 5x5 pixel window around the centre of the candidate, as this can be accurately found. The algorithm provides a good estimate of the radius, and so we are able to apply a narrow band of sizes of templates. All templates are pre-scaled to save on-line computation. Unless the sign has been damaged, its orientation is also known. The net result is that it takes less than one ms to classify a single candidate. Further, this computation can also take place on a separate processor.

With these detection algorithms we are able to give feedback within a few frames, ie., a fraction of a second. Currently, the accuracy levels are not adequate for a commercial system, however, such performance now appears to be likely in coming years. With such detection systems adapted to appropriately give information to older drivers it appears that assistance is plausible in the near future.

6 Conclusions

Difficulties reading road signs and visual acuity appear to be important influences on driver competency and safety for older people with ocular conditions. Given these findings, it may be that automated sign detection/recognition can enhance older individuals' ability to read traffic signs, and hence improve driver competency and safety, and delay driving cessation. Sign detection/recognition driver support systems may facilitate older adults maintaining their quality of life, mobility, independence and overall well-being. From a community perspective, these technologies also improve road safety for all road users. Current research in sign detection and recognition shows promising results in giving real-time feedback to drivers about critical signs, and with further research may have the potential to fulfil this role.

References

[Alonso *et al.*, 1997] J. Alonso, M. Espallargues, T. F. Anderson, S. D. Cassard, E. Dunn, P. Bernthpetersen, J. C. Norregaard, C. Black, E. P. Steinberg, and G. F. Anderson. International applicability of the vf-14 - an index of visual function in patients with cataracts. *Ophthalmology*, 104(5):799–807, 1997.

[Anstey *et al.*, 2005] K J Anstey, J Wood, S Lord, and J G Walker. Cognitive, sensory and physical factors enabling driving safety in older adults. *Clinical Psychology Review*, 25(1):45–65, 2005.

[Barnes and Loy, 2005] N Barnes and G Loy. Real-time regular polygonal sign detection. In *Proc. 5th Int Conf on Field and Service Robotics (FSR05)*, 2005.

[Barnes and Zelinsky, 2004] N Barnes and A Zelinsky. Real-time radial symmetry for speed sign detection. In *Proc IEEE Intelligent Vehicles Symposium*, Parma, Italy, 2004.

[Barnes *et al.*, 2005] N Barnes, G Loy, D Shaw, and A Robles-Kelly. Regular polygon detection. In *International Conference on Computer Vision*, 2005.

[Cassard *et al.*, 1995] S. D. Cassard, D. L. Patrick, A. M. Damiano, M. W. Legro, J. M. Tielsch, and *et al.* Reproducibility and responsiveness of the vf-14 - an index of functional impairment in patients with cataracts. *Archives of Ophthalmology*, 113(12):1508–1513, 1995.

[Dellinger *et al.*, 2001] A. M. Dellinger, M. Sehgal, D. A. Sleet, and E. Barrett-Connor. Driving cessation: What older former drivers tell us. *Journal of the American Geriatrics Society*, 49(4):431–435, 2001.

[Fletcher *et al.*, 2005] L Fletcher, G Loy, N Barnes, and A Zelinsky. Correlating driver gaze with the road scene for driver assistance. *Robotics and Autonomous Systems*, 52(1):71–84, 2005.

[Fonda *et al.*, 2001] Stephanie J. Fonda, Robert B. Wallace, and A. Regula Herzog. Changes in driving patterns and worsening depressive symptoms among older adults. *Journals of Gerontology Series B-Psychological Sciences & Social Sciences*, 56(6):S343–351, 2001.

[Friedman *et al.*, 2002] D. S. Friedman, J. M. Tielsch, S. Vitale, E. B. Bass, O. D. Schein, and E. P. Steinberg. Vf-14 item specific responses in patients undergoing first eye cataract surgery: can the length of the vf-14 be reduced? *British Journal of Ophthalmology*, 86(8):885–891, 2002.

[Gilhotra *et al.*, 2001] J. S. Gilhotra, P. Mitchell, R. Ivers, and R. G. Cumming. Impaired vision and other factors associated with driving cessation in the elderly: the blue mountains eye study. *Clinical & Experimental Ophthalmology*, 29(3):104–107, 2001.

[Haymes *et al.*, 2002] S. A. Haymes, A. W. Johnston, and A. D. Heyes. Relationship between vision impairment and ability to perform activities of daily living. *Ophthalmic and Physiological Optics*, 22(2):79–91, 2002.

[Hsu and Huang, 2001] S H Hsu and C L Huang. Road sign detection and recognition using matching pursuit method. *Image and Vision Computing*, 19:119–129, 2001.

[Ivers *et al.*, 2000] R. Q. Ivers, P. Mitchell, and R. G. Cumming. Visual function tests, eye disease and symptoms of visual disability: a population-based assessment. *Clinical & Experimental Ophthalmology*, 28(1):41–47, 2000.

[Katz and Yelin, 2001] P. Katz and E. Yelin. Activity loss and the onset of depressive symptoms: Do some activities matter more than others. *Arthritis and Rheumatism*, 44:1194–1202, 2001.

[Lord and Dayhew, 2001] S.R. Lord and J. Dayhew. Visual risk factors for falls. *Journal of the American Geriatrics Society*, 49:508–515, 2001.

[Loy and Zelinsky, 2003] G Loy and A Zelinsky. Fast radial symmetry for detecting points of interest. *IEEE Trans Pattern Analysis and Machine Intelligence*, 25(8):959–973, Aug. 2003.

[Lyman *et al.*, 2002] S. Lyman, S. A. Ferguson, E. R. Braver, and A. F. Williams. Older driver involvements in police reported crashes and fatal crashes: trends and projections. *Injury Prevention*, 8(2):116–120, 2002.

[Marottoli *et al.*, 2000] Richard A. Marottoli, Carlos F. Mendes de Leon, Thomas A. Glass, Christianna S. Williams, Jr. Cooney, Leo M., and Lisa F. Berkman. Consequences of driving cessation: Decreased out-of-home activity levels. *Journals of Gerontology Series B-Psychological Sciences & Social Sciences*, 55(6):S334–340, 2000.

[Marshall *et al.*, 2002] S. C. Marshall, R. Spasoff, R. Nair, and C. van Walraven. Restricted driver licensing for medical impairments: Does it work? *Canadian Medical Association Journal*, 167(7):747–751, 2002.

[Miller *et al.*, 1998] T. R. Miller, D. C. Lestina, and R. S. Spicer. Highway crash costs in the united states by driver age, blood alcohol level, victim age, and restraint use. *Accident Analysis & Prevention*, 30(2):137–150, 1998.

[Miura *et al.*, 2000] J Miura, T Kanda, and Y Shirai. An active vision system for real-time traffic sign recogntition. In *Proc 2000 IEEE Int Vehicles Symposium*, pages 52–57, Oct 2000.

[Owsley *et al.*, 1999] C. Owsley, B. Stalvey, J. Wells, and M. E. Sloane. Older drivers and cataract: Driving habits and crash risk. *Journals of Gerontology Series A-Biological Sciences & Medical Sciences*, 54(4):M203–M211, 1999.

[Owsley *et al.*, 2001] C. Owsley, B. T. Stalvey, J. Wells, M. E. Sloane, and G. McGwin. Visual risk factors for crash involvement in older drivers with cataract. *Archives of Ophthalmology*, 119(6):881–887, 2001.

[Owsley *et al.*, 2002] C. Owsley, G. McGwin, M. Sloane, J. Wells, B. T. Stalvey, and S. Gauthreaux. Impact of cataract surgery on motor vehicle crash involvement by older adults. *Journal of the American Medical Association*, 288(7):841–849, 2002.

[Paclik *et al.*, 2000] P Paclik, J Novovicova, P Somol, and P Pudil. Road sign classification using the laplace kernel classifier. *Pattern Recognition Letters*, 21:1165–1173, 2000.

[Pager, 2004] Chet K. Pager. Assessment of visual satisfaction and function after cataract surgery. *Journal of Cataract & Refractive Surgery*, 30(12):2510–2516, 2004.

[Piccioli *et al.*, 1996] G Piccioli, E De Micheli, P Parodi, and M Campani. Robust method for road sign detection and recognition. *Image and Vision Computing*, 14(3):209–223, 1996.

[Preusser *et al.*, 1998] D. F. Preusser, A. F. Williams, S. A. Ferguson, R. G. Ulmer, and H. B. Weinstein. Fatal crash risk for older drivers at intersections. *Accident Analysis & Prevention*, 30(2):151–159, 1998.

[Priese *et al.*, 1994] L. Priese, J. Klieber, R. Lakmann, V. Rehrmann, and R. Schian. New results on traffic sign recognition. In *Proc. Intelligent Vehicles Symposium*, pages 249–254, Paris, Aug. 1994. IEEE Press.

[Rochtchina *et al.*, 2003] E. Rochtchina, B. N. Mukesh, J. J. Wang, C. A. McCarty, H. R. Taylor, and P. Mitchell. Projected prevalence of age-related cataract and cataract surgery in australia for the years 2001 and 2021: pooled data from two population-based surveys. *Clinical And Experimental Ophthalmology*, 31(3):233–236, 2003.

[Rovner and Casten, 2002] B. W. Rovner and R. J. Casten. Activity loss and depression in age-related macular degeneration. *American Journal of Geriatric Psychiatry*, 10(3):305–310, 2002.

[Steinberg *et al.*, 1994] E. P. Steinberg, J. M. Tielsch, O. D. Schein, J. C. Javitt, P. Sharkey, and *et al.* The vf-14 - an index of functional impairment in patients with cataract. *Archives of Ophthalmology*, 112(5):630–638, 1994.

[Verbaken and Johnston, 1986] J. Verbaken and A. Johnston. Population norms for edge contrast sensitivity. *American Journal of Optometrics and Physiological Optometry.*, 63:724–732, 1986.

[Verbrugge, 1990] L. M. Verbrugge. The iceberg of disability. In S. Stahl, editor, *,The Legacy of Longevity: Health and Health Care in Later Life.*, pages 55–75. Sage Publications, CA, 1990.

[West *et al.*, 2002] C. G. West, G. Gildengorin, G. Haegerstrom-Portnoy, M. E. Schneck, L. Lott, and J. A. Brabyn. Is vision function related to physical functional ability in older adults? *Journal of the American Geriatrics Society*, 50(1):136–145, 2002.