Introduction

Visual fields, Mobility and Driving
1 Visual fields

1.1 Characteristics of the normal visual field

The visual field is defined as the portion of space in which objects are visible to the steadily fixating eye. The outer limit for each eye extends approximately 60 degrees nasally, 90 degrees temporally, 50 degrees superiorly, and 70 degrees inferiorly. Retinal sensitivity is greatest in the foveal area and decreases in relation to the distance from the fovea (eccentricity). The visual field has therefore been described as an ‘island hill of vision surrounded by a sea of blindness’ (Figure 1). Objects nearest to the fixation point are seen with greatest clarity, as though they were situated on a peak directly below the observer’s eye. As the contour of the hill slopes downward and outward from the peak toward the shoreline, smaller objects become invisible and only stimuli of gradually increasing size or intensity are seen (Figure 1). Eccentricity, thus, has a large effect on visual acuity. In the normal eye with visual acuity of 1.0 at fixation, acuity decreases rapidly in the peripheral field so that at 2 degrees from fixation it is reduced to 0.7. At 3 degrees, visual acuity is approximately 0.5; at 5 degrees it is 0.3; at 10 degrees, visual acuity is 0.2; at 20 degrees, visual acuity is 0.1; and at 40 degrees, it is about 0.05 (Harrington & Drake, 1990).

An area of complete blindness within the visual field of one eye is the physiological blind spot (Figure 1). The blind spot is the area of the retina where the retinal ganglion cells collect, become the optic nerve, and leave the eye. On a visual field chart, it is typically located 15 degrees temporally and 1 to 2 degrees inferiorly to the fovea. It extends for approximately 5 degrees horizontally and 7 degrees vertically. It is an area of complete blindness. The binocular field is made up of the overlapping
uniocular fields. A central portion is common to both eyes with an average diameter of approximately 120 degrees. The blind spot of each eye is covered by an intact portion of the visual field of the other eye. The horizontal diameter of the binocular visual field extends for 180 degrees. The size of the visual field as assessed by a given stimulus size and luminance can be influenced by age, media clarity, miosis, refractive errors, aphakia, and experience with the testing procedure.

1.2 Assessing the visual field

There are many ways to assess the extent of the visual field: confrontation testing (Donders), Amsler grid, manual or computerized testing, static or kinetic perimetry. The aim of perimetry is to examine visual acuity in all portions of the visual field quantitatively. Visual field impairments may be manifested by a field constriction, a general depression or by areas of reduced or absent vision (i.e. scotomas).

Most manual perimetry methods, such as the Goldmann perimeter (Figure 2), rely on kinetic techniques. When performing kinetic perimetry, a stimulus is chosen and moved throughout the visual field to determine the region in which it is visible.

![Figure 2. Example of output of Goldmann perimetry.](image)

Standardized test strategies specifying the speed and direction of the test object are used to scrutinize the visual field. Areas of equal sensitivity are delimited by isopters. Determining multiple isopters and then outlining them one on top of the other gives the two-dimensional picture of the island hill of vision, i.e. the visual field. One of the main advantages of kinetic perimetry is that relatively large areas of the field can be traversed in a fairly short time. The examiner can adjust the size and intensity of the test object, the area being tested and the speed with which various areas are tested.
Most computerized perimeters, such as the Humphrey Field Analyzer (HFA) (Figure 3) are static. When performing static perimetry, a test site and stimulus size are chosen and the stimulus intensity is varied until it is bright enough for the patient to see it. The numerical threshold printout available from computerized perimeters represent sensitivity values in decibels (dB). The advantage of computerized perimetry is that it can be standardized and reproduced and that it is less subject to examiner bias. Selection of test points, stimulus intensity values and how they are varied, order or presentation of stimuli, recording of patient responses, monitoring of fixation, performance of ‘catch trials’ as measures of reliability, are all functions easily adapted to machines.

**Figure 3.** Example of output of HFA perimetry.

### 1.3 Ocular pathology resulting in visual field defects

Visual field defects are caused by damage to the retina, the visual pathways, or the visual cortex. A defect in the macular area of the retina results in central visual field defects. The macula contains the foveola. The foveola is the thinnest part of the retina and subserves the most acute vision. Therefore, central visual field defects impair visual acuity. When the retinal area outside the macula is involved, peripheral visual field defects emerge. In case of peripheral visual field defects, visual acuity will remain intact. In this paragraph, three ocular diseases resulting in severe visual field defects are
discussed: age-related macular degeneration, glaucoma and retinitis pigmentosa. A schematic drawing of the eye is presented in Figure 4.

![Schematic representation of the human eye.](image)

**Figure 4.** Schematic representation of the human eye.

1.3.1 Age-related macular degeneration

Age-related macular degeneration (ARMD) is the leading cause of visual impairment in the Western World. It is a bilateral disease. The average age of visual loss in the first eye is 65 years, with about 12% incidence of involvement of the second eye each year. Prevalence of the final stage of ARMD is 1% of persons between 65 and 74 years of age and 11% of persons older than 84 years of age.

The most common complaint of patients with ARMD is blurring of central vision or an alteration in image shape (metamorphopsia). Some patients notice a hole (scotoma) in the center of the visual field. Other, yet rare, symptoms of macular disease are a decrease in image size (micropsia) or an increase in image size (macropsia). Frequently the earliest clinical manifestation of ARMD is the appearance of small, discrete, yellow-white spots, called drusen. These lesions are usually distributed symmetrically in both fundi. The exact role of drusen in the pathogenesis of ARMD is still unclear. Features associated with an increased risk of subsequent visual loss are focal hyperpigmentation and confluent drusen, particularly if one eye has already developed visual loss from ARMD. Two main types of ARMD are recognized: non-exudative and exudative.

1.3.1.1 Non-exudative ARMD

Non-exudative (dry, geographical or areolar atrophy) is the most common type of ARMD. It typically causes a gradual mild to moderate impairment of vision over several months or years. This type of ARMD is either due to a slow and progressive atrophy of the RPE (retinal pigment epithelium) and photoreceptors or follows collapse of an RPE detachment.
1.3.1.2 *Exudative ARMD*

Exudative (or neovascular) ARMD is less common than the non-exudative type but its effect on vision are frequently devastating. Patients with exudative ARMD may lose all central vision within a few days. Exudative ARMD may occur in isolation or in association with non-exudative ARMD. Two important features of exudative ARMD are RPE detachment and choroidal neovascularization. Detachment of the RPE is caused by the separation of the RPE from Bruch’s membrane by serous fluid. Choroidal neovascularization is the development of new vessels. Leakage of these new and weak vessels causes abrupt and severe visual loss.

1.3.1.3 *Treatment*

There is no effective treatment apart from the provision of low vision aids. In the final stage of ARMD, visual acuity is typically below 0.1. In case of exudative ARMD, argon laser photocoagulation may be effective in obliterating new vessels. Treatment by argon laser photocoagulation is effective in reducing the risk of severe visual loss by more than 50% but meticulous follow-up is required to detect persistence or recurrence of the neovascularization.

1.3.1.4 *Visual field defects*

Central visual field defects are best assessed by a static perimeter assessing the central 10 degrees. Perimetry reveals that foveal threshold is reduced. Central visual field defects may be manifested as depression of visual sensitivity in the central area of the field or as an absolute defect (i.e. no response is given to the brightest and largest stimulus). In case of hemorrhage from subretinal neovascularization, the central scotoma is irregular and dense.

1.3.2 **Glaucoma**

Glaucoma is a name given to a group of diseases in which the ganglion cells have been damaged. Damage is related to but not exclusively caused by an elevation of intraocular pressure (IOP). The principal factors determining the level of IOP are the rate of aqueous humor production and the resistance encountered in the outflow channels. Three main groups of glaucoma are distinguished: primary glaucoma, secondary glaucoma (e.g., due to trauma), or congenital glaucoma. Two main types of primary glaucoma are of interest here: open angle glaucoma and angle-closure glaucoma.

1.3.2.1 **Primary open-angle glaucoma**

Primary open glaucoma is characterized by an elevated IOP, an open angle, a glaucomatous cupping of the optic disk and visual field loss. The rise in IOP is caused by increased resistance of the drainage channels. It is a chronic, slowly progressive, usually bilateral disease with a insidious onset. It is the most prevalent of all glaucomas affecting approximately 1 in 200 of the general population over the age of 40 years. Men are more often affected than women. Prevalence of glaucoma
increases with advancing age and is approximately 10% for persons older than 80 years of age. Primary open-angle glaucoma is frequently inherited. Because of its insidious onset, primary open-angle glaucoma is usually asymptomatic until it has caused a significant loss of visual field. The initial therapy of primary open-angle glaucoma is medical. The aim of the treatment is to preserve the visual field by reducing IOP. In most cases the medical therapy is started with beta-blockers, reducing the aqueous humor production. If beta-blockers are ineffective, additional medical therapy is started or argon laser trabeculoplasty is performed. Argon laser trabeculoplasty causes a shrinkage of the collagen on the inner surface of the trabecular ring and contracts it inwards, thereby opening the intertrabecular spaces and increasing aqueous outflow. Finally, filtration surgery (trabeculectomy) can be considered.

1.3.2.2 Primary angle closure glaucoma
Primary angle-closure glaucoma is a condition in which obstruction to aqueous outflow is brought about solely by closure of the angle by the peripheral iris. It occurs in anatomically predisposed eyes, and is frequently bilateral. The disease affects approximately 1 in 1000 individuals over the age of 40 years, affecting females more commonly than males by a ratio of four to one. Like primary open-angle glaucoma it has a genetic basis. Progression of primary angle-closure glaucoma may be intermittent or acute. Symptoms of acute primary angle-closure glaucoma include rapidly progressive impairment of vision, pericocular pain, and congestion of the eye. The rapidly increased IOP may cause nausea and vomiting. Symptoms of intermittent primary angle-closure glaucoma are transient impairment of vision associated with haloes around lights. Treatment of acute primary angle-closure glaucoma is essentially surgical, although the initial treatment is medical. Medical treatment aims at pulling the peripheral iris away from the angle and at lowering the production of aqueous humor. Surgery (laser iridotomy or peripheral iridectomy) is applied to facilitate the transfer of aqueous humor from the posterior chamber to the anterior chamber, thus avoiding the iris to bow anteriorly.

1.3.2.3 Visual field defects
The progressive field changes in glaucoma include: 1) general depression of peripheral and central isopters, 2) formation of a nerve fiber bundle defect (arcuate scotoma) and/or formation of a nasal step defect, 3) rapid peripheral contraction (especially in the nasal field), 4) loss of the central field, 5) retention of a small, temporal island of vision, and 6) blindness. Once the late stages of the disease have been reached, the field loss may progress rapidly.

1.3.3 Retinitis pigmentosa (RP)
Retinitis pigmentosa is a generic name for a group of inherited diseases characterized by night blindness and constricted visual fields. Typical RP is a diffuse, usually bilaterally symmetrical, retinal dystrophy. Although both rods and cones are involved, damage to the rod system is predominant in the early stage. Prevalence of RP is 1 out of 4000. Age of onset, rate of progression, amount of
eventual visual loss, and the presence or absence of associated ocular features are related to the mode of inheritance. The autosomal recessive inheritance is the most common mode of inheritance. As the X-linked recessive form, it is a severe form of RP with early development of night blindness, visual field loss and cataract. At the end stage, visual acuity may be below 0.1 at the age of 50 years. The autosomal dominant type has a fairly benign course so that night blindness and visual field loss may not develop until adult life and cataract may not be a problem until the sixth decade of life. There is no effective treatment apart from the provision of low vision aids. Associated ocular diseases (such as cataract) can be treated.

1.3.3.1 Visual field defects
The earliest symptom is a ring scotoma occupying the midperiphery of the visual field. This defect commonly starts as a group of isolated scotomas in the region 20 to 25 degrees from fixation. These scotomas gradually coalesce to form a partially and finally a complete ring. The outer ring edge may expand peripherally at a fairly rapid pace, whereas the inner margin contracts very slowly toward fixation. Long after the entire peripheral field is gone, a small oval remnant of intact central field, resembling the final stage of glaucoma, remains.

2 Visual fields and mobility

“Orientation can be defined as establishing one’s position with respect to the environment, while mobility is the ability to navigate within it (Faye, 1976). Orientation and mobility on a practical level is considered ‘the ability to travel through the environment in a safe, efficient and independent manner, maintaining a planned route and at a speed close to normal walking pace’ (Lovie-Kitchin et al., 1990).” (Black et al., 1997). Mobility refers to the ability to navigate through an environment and as such driving can be considered as a specific case of mobility. Like mobility, driving requires the ability to navigate within an environment in a safe, efficient and independent manner at an acceptable speed. In this Ph.D.-thesis, the definition of mobility is restricted to walking and is discussed separately from driving.

As a lot of information in the environment is visual, it can be assumed that vision is an important determinant for safe and independent navigation through the environment. In the next sections the relationship between visual field on the one hand and mobility and driving on the other hand will be discussed. The effect of visual field loss on mobility and driving performance is compared to the effect of other primary vision parameters, such as visual acuity and contrast sensitivity, and to the effect of other parameters such as scanning ability, avoidance behavior or attentional capacities. Studies focussing on the relationship between vision and mobility and vision and driving will be reviewed.
2.1 Population-based studies

Rubin, Bandeen-Roche, Huang, Munoz, Schein, Fried, & West (2001) assessed perceived visual (dis)ability in a population-based sample of 2520 individuals of 65 years of age and older. Perceived visual (dis)ability was assessed by means of a questionnaire. Subjects were asked to rate 21 activities, such as walking down steps, reading street signs, seeing faces across the street on a five point scale ranging from ‘unable to perform because of vision problems’ to ‘no difficulty’. The items were classified on three subscales: a near-vision subscale (e.g. writing checks), a far-vision subscale (e.g. reading street signs across the street) and a night-time driving subscale (e.g. driving at night with oncoming headlights). The overall score also comprised items that were not included in the subscales, such as driving during the day and seeing faces across the street. As the far-vision subscale includes mobility-related activities only the results related to this subscale will be discussed here. The results on driving will be reported elsewhere (section 3.1). The far-vision subscale comprised activities such as walking down steps in dim light and during daylight, reading street sings at night and in daylight and a non-mobility related item, i.e. watching television. Visual acuity under normal and low (5.2 cd/m2) illumination, contrast sensitivity, glare, stereoacuity and visual fields were measured. Visual acuity was assessed with the ETDRS chart, contrast sensitivity was assessed with the Pelli-Robson chart and the visual fields were tested separately for each eye using the Humphrey Field Analyzer. The effects of demographic factors, cognitive status, depression and number of other chronic medical conditions were adjusted for. Results are presented as odds ratios. The odds of an event occurring (e.g. reporting no difficulty) are defined as the ratio of the probability that it will occur to the probability that it will not occur. The odds ratio is the ratio of the odds of a condition (e.g. good visual acuity) to the odds of another condition (e.g. impaired visual acuity). If the odds ratio is greater than 1, the event (e.g. reporting no difficulty) is more likely to occur in the first condition (e.g. good visual acuity) than in the second condition (e.g. impaired visual acuity). Results showed that comparing individuals in whom visual acuity differed by a factor two (0.3 logMAR), those with better vision were five times more likely (odds ratio = 5.17) to report least difficulty (as opposed to most difficulty) with activities involving far vision. A factor of two reduction in contrast sensitivity (0.3 log CS) was associated with an odds ratio of 4.38. These results indicate that a reduction in visual acuity and contrast sensitivity is related to an increase in the number of self-perceived disability. The association between self-perceived disability and a factor of two reduction in other vision variables was weaker; the odds ratios being 2.14 for glare sensitivity, 1.64 for stereo-acuity, 1.78 for central visual field, 2.02 for peripheral visual field and 1.29 for low luminance visual acuity.

2.2 Artificially restricted vision

Pelli (1987) artificially restricted vision of normally sighted subjects and assessed time to travel and number of bumps (contacts and full stops) while walking in a laboratory maze and a shopping mall. The visual field was restricted by a truncated paper cone and the diameter varied from 1 degree up to
60 degrees. Contrast was reduced by various concentrations of diamonds suspended in a clear plastic disk and varied from 0.3% up to 100% of normal contrast. Acuity varied from 0.003 to 1.0. Mobility performance was scored in terms of time to travel and number of bumps (contacts and full stops). Pelli observed that performance was only slightly impaired for degrees of vision from normal down to very restricted vision. Beyond this point, performance worsened quickly (Figure 5).

![Figure 5. Critical point of mobility performance (Pelli, 1987)](image)

The critical point (the severest restriction at which performance is only slightly impaired) in the maze was a 10 degree field (diameter), visual acuity of 0.01 and 4% of normal contrast. The corresponding critical points in the mall were a 4 degree field (diameter), visual acuity of 0.01 and 2% of normal contrast.

### 2.3 Ocular pathology (mixed groups)

*Marron and Bailey* (1982) assessed mobility performance in 19 low vision patients from a rehabilitation center. Visual acuity ranged from 0.03 to 0.63, log contrast sensitivity ranged from 0.60 to 1.42 and the remaining visual field within 40 degrees radius ranged from 4% to 98%. Subjects were asked to walk an inside and an outside route. The inside route consisted of a corridor with paper cylinders as obstacles. The outside course consisted of a route around a rectangular city block that included a series of obstacles differing in spatial detail and contrast. Error scores, such as making contact with an obstacle or becoming disoriented were recorded. Log peak contrast sensitivity and log percentage visual field correlated moderately with mobility performance (partial $r = 0.57$ and 0.50 respectively) whereas logMAR visual acuity did not correlate at all ($r = 0.07$). Visual field and contrast sensitivity explained 53% of the variance in mobility performance.

*Long, Rieser, and Hill* (1990) assessed the number of mobility incidents (e.g. loss of balance, object contact, off path) of 22 participants with low vision. Subjects were asked to walk a route in a classroom building, in a residential area and in a small business area under normal and reduced illumination conditions. Visual acuity in this group ranged from 0.03 to 0.5 and log contrast sensitivity ranged from 0.70 to 2.94. The number of points seen in a perimeter (140° field of view) ranged from 25% to 100%. Contrast sensitivity was found to be significantly correlated to mobility ($r=0.37$), whereas visual acuity
was not \( r=0.07 \). Visual field was significantly correlated with mobility incidents \( r=-0.38 \). Regression analysis revealed that 39% of the variance in mobility is accounted for by contrast sensitivity and visual field, whereas the addition of visual acuity explains only 4% more of the variance. 

_Lovie-Kitchin, Mainstone, Robinson and Brown (1990)_ assessed mobility performance (time to travel and number of errors) of 9 low vision patients and 9 control subjects. Low vision patients had best eye corrected visual acuity of 0.4 or less. Three subjects had a central scotoma, all other low vision subjects had paracentral or pericentral visual field losses, i.e. the central field was preserved. Control subjects had distance visual acuities of 0.8 or better in each eye and normal visual fields. The visual field was subdivided into 15 divisions to assess the relative importance of different parts of the visual field (Figure 6). Mobility performance was assessed by means of an indoor course with boundaries marked as white strips on gray carpet. The path wound its way through and around 87 obstacles. Subjects walked the route under low and reduced illumination conditions. They were instructed to walk at a steady and comfortable pace, to remain within the boundaries of the pathway and to avoid contact with obstacles. The low vision group was significantly slower than the controls and made significantly more errors. There was no significant relationship between visual acuity of the low vision group and mobility scores (time nor errors). The angle subtended by the binocular visual field correlated significantly with time taken to traverse the course \( r = -0.55 \) and the number of errors \( r = -0.76 \). The central area (37 degrees radius) was significantly related to travelling time with correlation coefficients ranging from -0.79 to -0.84. The left, right and inferior mid-peripheral areas (37-58 degrees radius) also played a significant role in determining travelling time (correlation coefficients ranging from -0.75 to -0.79).

![Figure 6. Important areas for mobility (Lovie-Kitchin et al. 1990). C: central, IC: inferior central, SC: superior central, LMP: left mid-periphery, RMP: right mid-periphery, LP: left periphery.](image)

_Kuyk, Elliott, and Fuhr (1998)_ tested 87 low-vision subjects on a real world mobility course laid out in the hallways of a rehabilitation center. Sixty-six different low-vision subjects were tested on an outdoor course laid out in a residential/small business setting. Both routes were assessed under normal and reduced illumination conditions. Subjects were instructed to walk the courses at a comfortable pace.
and without interruption, to maintain safety and to avoid contacting obstacles. Time to complete the course and the number of mobility incidents, such as object contacts and searches with hands and feet were recorded. Visual acuity, contrast sensitivity and visual field extent were assessed. To obtain a measurement of scanning ability, subjects were asked to locate, in sequence, as many numbered targets as possible that were randomly distributed on a black and white photograph of a street scene. Other variables included glare disability, color confusion, figure-ground, embedded figures, contrast sensitivity and peak frequency of stationary and drifting gratings. On the basis of stepwise regression analysis and depending on the route, illumination and dependent variable it was observed that 30% to 42% of the variance could be accounted for by a subset of the vision variables. Visual field extent and scanning ability were the two most important predictor variables in all of these predictive models.

Summary

The population-based study by Rubin et al. (2001) indicates that visual acuity is the primary determinant of the level of difficulty subjects perceive when performing mobility related tasks. Contrast sensitivity was reported as the second most important determinant of self-perceived difficulty. Other vision variables such as visual field seem to play a minor role. In contrast, mobility performance in groups with visual impairments could not be predicted at all on the basis of visual acuity. Contrast sensitivity and visual field measures were the primary predictors, explaining 39 to 53 percent of the variance in mobility performance (Marron & Bailey, 1982; Long et al., 1990).

According to the studies of Lovie-Kitchin et al. (1990) and Pelli (1987), the central area seems to be the most important area for mobility. This finding is in contrast to the general assumption that individuals with substantial peripheral visual field loss due to, for example glaucoma or retinitis pigmentosa (RP) demonstrate much greater difficulty with mobility than individuals with central visual field loss due to conditions such as senile macular degeneration (Marron & Bailey, 1982; Szlyk, Pizzimenti, et al. 1995). The effect of specific ocular pathology on mobility will be discussed below.

2.4 Specific ocular pathology

2.4.1 Macular Degeneration (MD)

Szlyk, Fishman, Grover, Revelins, & Derlacki (1998) asked 72 patients with juvenile macular dystrophies to rate the level of difficulty they experienced in performing everyday activities on a 5-point scale ranging from ‘no difficulty’ to ‘not able to perform the activity’. Their scores were compared to the responses of 120 RP patients. Factor analysis revealed six factors, including activities involving central vision (e.g. reading ingredients on cans of food), mobility (e.g. walking through shopping malls), negotiating steps (e.g. walking down steps in dim light), eating, driving (e.g. driving in unfamiliar areas) and miscellaneous (e.g. grooming, watching television). The activities that were reported as more difficult by the patients with macular dystrophies were the activities including central vision, the items in the miscellaneous category and the item ‘finding particular items in a store (mobility)’. The items that were reported to be more difficult for the patients with RP included mobility.
(except 'finding particular items in a store') and negotiating steps. Driving was a category with the lowest participation. Approximately 63% of subjects with macular dystrophies and approximately 23% of subjects with RP reported to have quit driving for non-visual reasons.

Kuyk and Elliott (1999) studied 41 subjects with macular degeneration. Walking speed and number of mobility incidents were recorded while subjects walked three different courses (a high density obstacle course in a laboratory, an indoor hallway course and an outdoor course). Stepwise regression was used to develop predictive models for the three mobility courses and for both dependent variables (walking speed and number of incidents). Significant models were found for the six analyses. Selection of the predictor variables in the different models depended on the task at hand. For example, scanning ability was a significant predictor for the course where there were many turns and a very high density of objects at different levels. Log contrast sensitivity was the most important predictor as it was included in five out of six models. Visual field extent was included in only three out of six models. Visual acuity was not a significant predictor. Vision scores could account for 30% to 60% of the variance in mobility performance.

2.4.2 Retinitis Pigmentosa (RP)

Haymes, Guest, Heyes, and Johnston (1996) assessed mobility performance on three real world mobility routes. The routes were laid out in a quiet residential street, an outdoor small business area and an indoor suburban shopping center. Subjects were instructed to walk each route at a comfortable walking pace, without a mobility aid and wearing any habitual refractive correction. Number of contacts and percentage preferred walking speed (PPWS) were recorded. PPWS is a commonly used parameter of mobility and is derived from the preferred walking speed. The preferred walking speed is determined by measuring the time taken to walk an unobstructed path at a normal and comfortable pace. The mean time to walk the test course is then expressed as the percentage of the preferred walking speed. Visual acuity, contrast sensitivity, visual field extent and RP concentric field rating were assessed. RP concentric field rating is the degree to which a large loss of the peripheral visual field extends into the central visual field. Eighteen subjects with RP participated in this study. The number of contacts as dependent variable was excluded from analysis as contacts were rarely observed. Differences in mobility performance were clearest for the indoor shopping mall route. Visual acuity, Pelli-Robson contrast sensitivity, Melbourne Edge Test contrast sensitivity and RP concentric field rating correlated significantly (r>.70) with PPWS. Pelli-Robson contrast sensitivity and RP concentric field rating explained 64% of the variance.

Black, Lovie-Kitchin, Woods, Arnold, Bymes, and Murinish (1997) assessed safety (error score) and efficiency (PPWS) of mobility performance on an indoor course in 10 RP patients and 9 age-matched controls. Each subject walked through the course twice, once under high (range: 300-570 lux) illumination and once under low (range: 15-41 lux) illumination. The subjects with RP were significantly slower and made significantly more errors than did the control subjects. Illumination showed a significant effect on error scores and PPWS for the RP group but not for the controls. Within the RP
group, neither visual acuity nor contrast sensitivity was significantly correlated with mobility measures while average visual field extent was correlated with all measures except low illumination PPWS. Best predictors of mobility performance were visual field extent alone ($R^2=0.57$ for high illumination PPWS, $R^2=0.66$ for high illumination error score) or in combination with contrast sensitivity ($R^2=0.54$ for low illumination PPWS). Low illuminance error score could be predicted by visual field, contrast sensitivity and visual acuity ($R^2=0.75$).

Szyk, Fishman, Alexander, Revelins, Derlacki, & Anderson (1997) assessed the level of perceived difficulty experienced by 167 patients with RP in the performance of everyday activities. Subjects were asked to rate activities such as mobility and driving on a difficulty scale, ranging from ‘no difficulty’ to ‘not able to perform’. Activities on which subjects reported a great degree of difficulty (activities that 20% or more of all patients were not able to perform for visual reasons) were driving at night, walking outdoors at night, reading street signs at night, seeing faces from across a street, threading a needle, and walking down steps during daylight and in dim light. Visual acuity, visual field and ERG data were obtained. Results on driving will be reported elsewhere (section 3.4.2). Visual acuity and visual field area (II4e isopter) were significantly correlated with all mobility related items (correlation coefficients ranging from .29 to .56). Visual field area (V4e isopter) and ERG parameters correlated significantly with the items walking outdoors at night, participating social gatherings, and walking through shopping malls but not with the items finding a seat in a movie theatre and finding particular items in a store. Multiple regression indicated that visual acuity and visual field (II4e) accounted for only 17% of the variation in perceived difficulty in mobility.

Geruschat, Turano, and Stahl (1998) evaluated the effects of RP on mobility performance (walking speed and mobility incidents) in a simple and complex environment. The simple course was laid out in a basement hallway and was seeded with paper cups. On this course, mobility was measured under normal (8.6 - 47.3 meter candles) and reduced illumination conditions. In the reduced illumination condition, the subject wore goggles of neutral density filters that reduced transmission to 11%. The complex course was laid out in the main corridor of a hospital and required the subjects to travel up and down stairs and to walk through glass doors. Subjects were instructed to walk a predefined course as quickly and safely as possible while avoiding all obstacles. The results of 25 RP patients were compared to the results of 16 controls. The results showed that RP subjects traveled more slowly than the normally sighted subjects and that both normally sighted and RP subjects traveled more slowly under reduced illumination. On the simple course, RP subjects were five times (odds ratio = 5.12) more likely to have a mobility incident under reduced illumination than the normally sighted subjects. Under normal illumination, RP patients were no more likely to have a mobility incident than the controls. Regarding the complex route, statistics could not be performed as none of the control subjects had a mobility incident. Of the RP subjects, six patients made more than three mobility incidents. Walking speed was significantly correlated with visual acuity, log peak contrast sensitivity, and visual field extent. On the complex course, 69% of the variance in the RP subjects' walking speed was accounted for by log contrast sensitivity and visual field extent.
Turano, Geruschat, Stahl and Massof (1999) asked 145 subjects in whom typical RP had been diagnosed to rate 35 mobility situations on a scale of 1 to 5. They were told that 1 meant “no difficulty” and 5 meant “extreme difficulty”. Part two of the questionnaire contained mobility-related questions, including “Have you fallen in the last year?” and “Do you limit travel by yourself due to your vision loss?”. In a subgroup of 32 patients, visual acuity, contrast sensitivity and visual field were assessed. Results indicated that four of the six most difficult mobility situations were related to lighting conditions: walking at night, adjusting to lighting changes, walking in dimly lit indoor areas, and walking in high-glare areas. Contrast sensitivity and visual field were significantly related to perceived visual ability for independent mobility (Spearman’s rho = 0.54 and 0.52), whereas age and visual acuity were unrelated. Multiple regression on the basis of all vision variables (logMAR, log contrast sensitivity, log retinal area II4e, log retinal area V4e) indicated that 57% of the variation in perceived difficulty for mobility was accounted for by these visual function measures.

Szlyk, Seiple, Fishman, Alexander, Grover, and Mahler (2001) studied self-reported performance and functionally assessed performance of daily activities in 62 individuals with RP. The self-report questionnaire consisted of 53 items designed to target daily activities that are potentially problematic for individuals with RP. Subjects were asked to rate themselves on a 5-point scale as to the level of difficulty they experienced in performing each activity. The functional assessment battery consisted of 64 tasks including near vision activities and orientation and mobility activities. Performance was evaluated by an orientation and mobility instructor and was coded on the same 5-point scale used in the self-report questionnaire. Szlyk and colleagues report significant correlations between the functional assessment and the self-report questionnaire for all but two of 32 items, indicating the reliability of self-report in assessing task difficulty. They further observed that contrast sensitivity correlated with most of the self-reported questionnaire items (93% of the questionnaire items correlated significantly) and the functional assessment items (89% correlated significantly). With regard to the relationship between vision parameters and performance, it was observed that subjects who had vision characteristics above threshold level had mild to no difficulty performing daily tasks. Threshold levels were 2000 degree2 visual field area, ERG amplitudes of 10 microV, log contrast sensitivity of 1.4, and visual acuity of 0.25 logMAR. In contrast, subjects who had vision characteristics below threshold level had variable degrees of difficulty performing the tasks. It is of particular interest that individuals with severe levels of vision loss could have minimal impairment in carrying out tasks of everyday life.

2.4.3 Glaucoma

Turano, Rubin, and Quigley (1999) compared mobility performance of 47 subjects with open-angle glaucoma with 47 persons with normal vision. Mobility performance (time to complete and number of mobility incidents) was recorded on a hallway and in a clinic waiting room. Glaucoma patients walked significantly slower (~10%) than normal-vision subjects. Although the number of subjects who had a mobility incident was almost twice as high in the glaucoma group (7) than in the normal-vision group...
the difference was not statistically significant. Walking speed was moderately correlated with logMAR ($r=-0.45$), log contrast sensitivity ($r=0.50$) and Esterman visual field score ($r=0.43$). An estimate of general loss of sensitivity across the visual field (MD, mean deviation) correlated most highly with walking speed ($r=0.57$).

*Nelson, Aspinall, & O’Brien (1999)* asked 63 patients with glaucoma to rate perceived difficulty of daily activities on a four point scale, ranging from “no difficulty at all” to “severe difficulty”. The activities or situations that created the most problems were activities involving lighting and glare and activities demanding functional peripheral vision, such as walking on steps or kerbs and crossing the road. With increasing severity of binocular visual field loss there was an increase in the number of self reported visual problems. Subjects with moderate visual field loss reported a general increase in difficulty with daily life activities as compared to subjects with mild visual field loss, but no difference could be found between the two groups when evaluating particular tasks. The difference between subjects with moderate and severe visual field loss was apparent on several tasks such as tripping over, going from a bright to a dark room or vice versa and confidence in going out in the street.

**Summary**

The study by Szlyk, Fishman, et al. (1998) directly compares the perceived difficulty of subjects with macular degeneration and retinitis pigmentosa on several daily activities. The results concur with the general assumption that patients with peripheral field defects experience more problems with mobility than subjects with central field defects, who report activities involving detailed vision as their major concern. The perceived difficulty with mobility is also observed in the study by Szlyk et al. (1997) and Turano, Geruschat et al. (1999) for RP patients and in the study by Nelson et al. (1999) for glaucoma patients.

Visual acuity was not a significant predictor of mobility in any of the ocular pathology groups. Parallel to the findings on the mixed pathology groups, visual field and contrast sensitivity are the major determinants of actual or perceived difficulty with mobility.

### 3 Visual fields and driving performance

Although mobility and driving share common features, the difference in speed is unmistakable. Increased speed and time pressure while driving may reveal major differences between ocular pathologies that were not visible for mobility. Likewise, good vision might become more important with increasing speed. If this were true, the predictive value of, for instance, visual acuity would be higher in case of driving than in case of mobility. The effect of vision parameters on driving performance will be addressed in the following sections.
3.1 Population-based studies

Johnson and Keltner (1983) performed an automated visual field screening of 10000 volunteers. Visual field results were correlated to driving conviction and accident records for a three-year period prior to the test date. Abnormal visual field loss was observed in 3.3% of the sample. Approximately 1.1% of the sample exhibited binocular visual field loss and in 0.3% of the sample the binocular loss was severe (e.g. hemianopic defect or severe visual field restriction). More than half (57.6%) of the individuals with visual field loss reported that they did not have eye problems. Accident rates and conviction rates (for a fixed number of kilometers) of subjects with visual field loss in both eyes were more than twice as high as for the age and sex matched control group with normal visual fields. Results of subjects with visual field loss in one eye did not differ from their controls.

Rubin, Bandeen-Roche, Huang, Munoz, Schein, Fried, & West (2001) assessed perceived visual (dis)ability in a population-based sample of 2520 individuals of 65 years of age and older. Perceived visual (dis)ability was assessed by means of a questionnaire. Subjects were asked to rate 21 activities, such as walking down steps, reading street signs, seeing faces across the street on a five point scale ranging from ‘unable to perform because of vision problems’ to ‘no difficulty’. The items were classified on three subscales: a near-vision subscale (e.g. writing checks), a far-vision subscale (e.g. reading street signs across the street) and a night-time driving subscale (e.g. driving at night with oncoming headlights). The overall score of the questionnaire also comprised items that were not included in the subscales, such as driving during the day or in unfamiliar areas. Visual acuity under normal and reduced illumination, contrast and glare sensitivity, stereoacuity, and central and peripheral visual field were assessed. The effects of demographic factors, cognitive status, depression and number of other chronic medical conditions were adjusted for. Only the findings on driving are reported here. Results showed that 79% of the participants reported driving during the day within the past three months. A reduced percentage of subjects (69%) reported driving at night and an even smaller percentage (40%) reported driving in unfamiliar areas. As has been observed in other studies, driving is an activity with the lowest participation. Although subjects reported to avoid driving for reasons unrelated to vision, the authors presume that vision might have played a role for some or even most of the participants. For the night-time driving subscale, the relationships with vision parameters were analyzed. Results showed that a factor of two reduction (0.3 log) in visual acuity and contrast sensitivity was associated with a three-fold odds ratio of reporting difficulty in night-time driving. The association with other variables was weaker: the odds ratios being 0.72 for low luminance acuity, 1.76 for glare sensitivity, 1.36 for stereoacuity, 1.76 for central visual field and 1.09 for peripheral visual field.

3.2 Artificially restricted vision

Wood and Troutbeck (1992) studied the importance of simulated visual field defects on driving performance in nine young, visually normal subjects. Driving performance was assessed in a test car on a closed-road circuit. The circuit was free of other motor vehicles and comprised a closed, bitumen
road containing hills, bends, straight stretches and standard road signs. Subjects were instructed to drive at what they felt was a safe speed with the constraint that they drove in their own lane, drove within the speed limits as indicated by road signs and that they obeyed all regulatory traffic signs. They were further instructed that they would be required to perform a number of concurrent tasks, including:

- **Peripheral awareness**: subjects had to detect and correctly identify road signs that were positioned along the roadside. They also had to report if they were aware of any people at the roadside.
- **Obstacle avoidance**: drivers were instructed not to contact or drive over cardboard boxes placed on the road surface,
- **Speed estimation**: along the straight stretch of the road, the subjects were instructed to drive at a speed of 60 km/h when the speedometer was obscured,
- **Stopping distance**: the distance that each subject traveled before stopping in response to an object thrown across the road,
- **Maneuvering**: subjects were instructed to drive through a winding course of two parallel lines of traffic cones at a comfortable speed without touching or knocking over any of the traffic cones,
- **Reversing**: the subject was required to reverse into a standard parking space delineated by white lines,
- **Vehicle position**: the road position of the car along the whole circuit was given an overall score
- **Time to complete the course**: the total driving time, measured from commencing the circuit to the start of the maneuvering and reversing tasks,
- **Overall driving score**: a score, calculated to assess the compensation for visual disability made either by taking longer to complete the course, by making more errors or by a combination of both.

Four visual field conditions were employed: baseline (full fields), monocular vision, binocular fields extending 40 degrees (diameter) and binocular fields extending 20 degrees (diameter). The visual impairments were suspended before the eyes in modified swimming goggles. The conditions with field restrictions of 40 degrees or less were impaired with regard to peripheral awareness, obstacle avoidance, maneuvering errors, time to complete the course and overall driving error score. No significant effect was observed on maneuvering time, reversing time, speed estimation or stopping distance. The monocular condition did not significantly affect performance for any of the driving tasks assessed.

*Wood and Troutbeck (1994)* studied the effect of simulated visual impairment on driving performance in 14 young adults, using the same methodology as Wood and Troutbeck (1992). The visual field manipulation resulted in binocular visual fields with a horizontal and vertical extent of 90 degrees (diameter). The monocular condition reduced the horizontal extent of the visual field to 105 degrees (diameter, with a blind spot at 15 degrees eccentricity). While driving, peripheral awareness, speed estimation, road position, driving time, maneuvering and reversing were assessed as described above. Additionally, reaction times were assessed by means of a central and a peripheral LED
mounted on the windscreen. On illumination of a LED, the subject was required to press the brake pedal as quickly as possible. Constriction of the binocular field to 90 degrees diameter resulted in slower driving (time to complete the course and reversing time) and an increase in reaction times (to the peripheral as well as to the central target). Scores on other aspects of driving, such as peripheral awareness, speed estimation and maneuvering were within normal limits. Monocular vision showed no significant effect on any of the driving measures except reversing time.

3.3 Ocular pathology (mixed groups)

Lövsund, Hedin and Törnros (1991) assessed driving capacity and the detection of stimuli in a driving simulator. Ten young controls, 10 older controls and 31 subjects with visual field defects participated in this study. Visual field defects ranged from local scotomas to hemianopic defects. All subjects had normal uncorrected visual acuity. Subjects were instructed to stay in the right lane of a two-lane road and to maintain a steady 100 km per hour throughout the test. While driving, a flickering black and yellow stimulus could appear upon which subjects had to respond by immediate braking. The stimulus could appear on any of 24 positions. The screen on which the road and stimuli were projected covered 120 degrees horizontally and 30 degrees vertically. All subjects showed good driving capacity as measured by speed variation and departure from right lane. The reaction times of the subjects with visual field defects were compared to the results of age-matched control subjects. For every position the median reaction time was determined. If the median reaction time exceeded the 90th percentile of the age-matched controls, the position was marked as impaired. If two or more (individual) reaction times were longer than 3 seconds or if two or more stimulus presentations were missed, the position was also marked as impaired. Several deviant points in the pathological field were considered as an indication that the subject did not compensate for the defect. Using this criterion, it was concluded that only 4 out of 31 subjects with visual field defects compensated. A second study was run to analyze the eye movement patterns while driving. Subjects who had shown compensatory capacities in the first study were compared to subjects with similar defects who had reduced detection capability. Although sample sizes are too small to draw firm conclusion, results suggest that subjects who compensated (i.e. had normal reaction time data) concentrated a much greater percentage of fixations to the affected side of their field while driving.

Szylk, Seiple, and Viana (1995) investigated the relative effects of age and compromised vision on driving-related skills and on-road accidents. Driving performance on an interactive driving simulator was assessed in 47 control subjects and in 60 subjects with compromised vision due to e.g. age-related macular degeneration, retinitis pigmentosa or hemianopia. Subjects were instructed to operate the simulator as they would normally drive their own car and to obey all traffic signs and signals along the roadway. Simulator indices such as mean speed, braking response and eye and head movements were recorded during an eight minute driving session. Results indicated that older subjects, whether visually compromised or not, performed more poorly on the simulator. No main effect of vision impairment nor an interaction effect between age and vision impairment was observed. However,
despite the poorer driving performance of the older group, the older drivers had no higher real-world accident rates than younger subjects. Szlyk and colleagues attribute the discrepancy between performance on the simulator and real-world accidents to compensatory mechanisms as they observed that older subjects showed reduced risk-taking, increased eye movements and reduced speed while driving. Vision impaired subjects also reported reduced risk-taking in real-world driving. Visual acuity and visual field extent along the horizontal meridian did not correlate with simulator indices (lane boundary crossings, braking response time, braking pressure, speed, simulator accidents). The degree of central field loss correlated only with speed (r=-0.43), whereas age correlated with all variables but braking pressure (correlation coefficients ranging from 0.31 to -0.46). Vision group status and degree of central field loss was (marginally) predictive of accident member group (no accidents versus at least one accident) whereas risk-taking was predictive of state conviction group membership.

Wood (1999) investigated the effects of age and visual impairment on driving performance. Fifteen (15) young subjects with normal vision, 26 older subjects with normal vision and 21 older subjects with early visual impairments (due to e.g. ARMD, cataract or glaucoma) were assessed on a closed circuit driving track as described by Wood and Troutbeck (1992). All subjects had binocular visual acuity of 0.5 or better. Peripheral awareness (road sign detection), reaction time (four LED’s), speed estimation and driving time were assessed as described above. Results indicated that older, visually impaired subjects performed worse than older, normally sighted subjects for peripheral awareness and that they performed worse than the young, normally sighted subjects for peripheral awareness, peripheral reaction times and time to complete the course. The effect of age between the normally sighted groups was significant for peripheral awareness and time to complete the course. Visual acuity was only significantly related to central reaction time (R²=0.08) and peripheral awareness (R²=0.11).

Summary
Like the studies on mobility, studies on driving performance indicate that visual acuity is a weak predictor (Szlyk, Seiple & Viana, 1995; Wood, 1999). The value of the visual field as a predictor is less unequivocal. Studies have shown that severe visual field defects result in impaired driving performance, as defined by conviction and accident rates (Johnson & Keltner, 1983) or driving performance indices, such as maneuvering errors, obstacle avoidance or peripheral awareness (Wood & Troutbeck, 1992). Less severe visual field defects, such as a field constriction of 90 or 105 degrees diameter result in slower driving but otherwise unimpaired driving performance (Szlyk, Seiple & Viana, 1995; Wood & Troutbeck, 1992, 1994). It is assumed that the reduction of driving speed is a compensatory mechanism that allows safe driving despite vision impairments (Szlyk, Pizzimenti et al., 1995; Wood & Troutbeck, 1992, 1994). Other compensatory mechanisms that might minimize the negative effects of vision impairment on driving are reduced risk-taking (Szlyk, Pizzimenti et al., 1995) and an increase of eye movements (Lövsund et al., 1991; Szlyk, Pizzimenti et al., 1995). In the next sections, driving performance and driving safety related to specific ocular pathology will be reviewed.
3.4 Specific ocular pathology

3.4.1 Macular Degeneration (MD)

Szlyk, Fishman, Severing, Alexander, and Viana (1993) evaluated driving performance of 20 subjects with juvenile macular dystrophies. Driving performance was defined by accident involvement as obtained through state records and self-report and by an evaluation of performance on a driving simulator. The findings of the central vision loss group were compared to the findings of 21 RP patients as reported by Szlyk et al. (1992). The proportion of individuals involved in accidents in the central vision loss group (35%) was comparable to that of the control group (38%). The RP group, in contrast, had a significantly greater likelihood of accident involvement (76%) than either the central vision loss group or the control group. For those who had not restricted their driving to daylight hours, the likelihood of night-time accident involvement for both the central vision loss group (31%) and the RP group (43%) was greater than for the control group (17%). The central vision loss group and RP group did not differ significantly with regard to night-time accident involvement. For the central vision loss group, no significant correlation was observed between the number of accidents and visual acuity, horizontal extent or the binocular area of the scotoma. For the RP group, visual field measures were significantly related to accident involvement. With regard to driving performance, simulator data revealed that more subjects in the central vision loss group (40%) and the RP group (38%) had at least one lane boundary crossing than subjects in the control group (21%). The two patients groups did not differ significantly. Braking response time to a stop sign was impaired for both patient groups, whereas braking response time to a traffic light was only impaired for the central vision loss group. Both patient groups had significantly lower risk-taking scores than the control group.

McCloskey, Koepsell, Wolf, and Buchner (1994) investigated whether ocular diseases increased the risk of motor vehicle collision injuries in older drivers. They compared 235 drivers who were treated for injuries sustained in a police-reported collision with 448 controls who were matched for age, sex and county residence. Macular degeneration was not associated with collision risk (OR = 0.9, n.s.).

Szlyk, Pizzimenti, Fishman, Kelsch, Wetzel, Kagan, and Ho (1995) compared driving performance of older subjects with and without ARMD. Ten men with the diagnosis of ARMD and 11 control subjects of comparable age participated in this study. Subjects underwent testing on an interactive driving simulator and performed a real-world on-road test. Real-world accidents were recorded by means of state reports and self report. Patients with ARMD had worse performance on vision indices, simulator indices (such as number of accidents and lane boundary crossings) and road test indices (such as speed, blind spot check while merging, proper use of signal, lane observance and overall driving score). Visual acuity, contrast sensitivity and dazzle recovery correlated with performance in the simulator (absolute correlation coefficients ranging from 0.43 to 0.79) and on the road test (absolute correlation coefficients ranging from 0.49 to 0.83). Vision did not correlate with on-road accidents. However, large differences between low-luminance and high-luminance acuity was related to increased number of day-time accidents (r=0.59) and rate of state convictions per mile (r=0.79). Higher cognitive abilities (e.g. visual form discrimination, digit span, line orientation) correlated with
better performance on the simulator and on the road test (absolute correlation coefficients ranging from 0.47 to 0.74). Lane boundary crossings, speed and accidents on the simulator were related to several indices of the driving test on the road (absolute correlation coefficients ranging from 0.50 to 0.83).

Real-world accident rates did not differ between the two groups. As patients with ARMD performed more poorly on the simulator and road test but as these differences did not translate into increased numbers of real-world accidents, it was hypothesized that drivers with ARMD compensated for their reduced driving skills by reducing speed and restricting their driving behavior (e.g. not driving in unfamiliar areas, no night-time driving). In favor of this hypothesis, it was observed that the ARMD group had lower, though not significantly different, mean self-reported risk-taking scores than the control group. Moreover, risk taking alone could predict accident group membership (no accident versus one or more accidents).

Owlsley, McGwin and Ball (1998) estimated odds ratios (OR) for the association between injurious and non-injurious motor vehicle crash involvement and visual impairment in a group of 294 licensed drivers of 55 years of age or older. The OR for macular degeneration was 3.3, indicating that subjects involved in injurious crashes were 3 times more likely to have MD compared to controls. For non-injurious cases, no significantly elevated crash risk was obtained.

3.4.2 Retinitis Pigmentosa (RP)

Fishman, Anderson, Stinson, and Haque (1981) evaluated driving performance of 42 patients with RP who had varying degrees of central and peripheral field loss. Subjects were interviewed regarding total number of driving years, usual driving hours per week, and involvement in moving collision violations within the last 5 years. Their results were compared to the results of 87 control subjects. A significant difference between the two groups existed for the number of accidents (50% accident free RP patients versus 71% accident free controls). However, this difference was largely attributable to a subgroup of female RP patients, who drove 1 to 10 hours per week and with 5 to 10 years driving experience. There was no relationship between vision indices and number of accidents. Most RP patients (74%) reported that they voluntarily restricted their driving to daylight hours.

Sztyk, Alexander, Severing, and Fishman (1992) assessed driving performance in 21 subjects with RP and 31 control subjects. Driving performance was assessed by means of a driving simulator and the number of on-road accidents that had occurred within the five years previous to the study (self report and state records). A greater proportion of subjects with RP had accidents, on the road (76% as compared to 39% in the control group) as well as on the driving simulator (14% versus 0%). For the RP group, most of the on-road accidents involved collisions with peripheral objects (83% as compared to 31% in the control group). Binocular horizontal field extent and binocular field area were best predictors of accidents. Only 33% restricted themselves to day-light driving. For those who did not restrict themselves to daytime driving (67%), the difference between the proportion night-time and
daytime accidents was comparable for the two groups (35% night-time versus 65% daytime accidents for the RP group and 38% night-time and 63% daytime accidents for the control group).

Szlyk, Fishman, Alexander, Revelins, Derlacki, & Anderson (1997) assessed the level of perceived difficulty experienced by 167 patients with RP in the performance of everyday activities. Subjects were asked to rate activities such as mobility and driving on a difficulty scale, ranging from ‘no difficulty’ to ‘not able to perform’. Activities on which subjects reported a great degree of difficulty (activities that 20% or more of all patients were not able to perform for visual reasons) were driving at night, walking outdoors at night, reading street signs at night, seeing faces from across a street, threading a needle, and walking down steps during daylight and in dim light. Visual acuity, visual field and ERG data were obtained. One third of patients (39%) reported not to drive anymore for nonvisual reasons. Visual acuity correlated significantly with driving at night (r=0.42) and driving in unfamiliar areas (r=0.45) but not with driving during the day. Visual field area (II4e) was only significantly related to driving during the day (r=0.38). None of the other parameters was significantly correlated to driving. Multiple regression indicated that visual acuity was the primary and sole predictor of perceived difficulty in driving, taking 14% of the variance into account.

3.4.3 Glaucoma

In a short report, MacKean and Elkington (1982) report 214 patients with glaucoma of whom 28.5% (61 patients) were still driving. Five (8%) of them said that they were aware of their field loss and that they had made allowances for it by turning their heads. Twenty patients (of 214, 9%) had given up driving because of the eye condition. Of these, 13 (65%) had a further eye disease (mostly cataract) and three (15%) had given up driving after accidents.

McCloskey, Koepsell, Wolf, & Buchner (1994) determined whether ocular diseases, such as glaucoma, increased the risk of motor vehicle collision injuries in older drivers. They compared 235 drivers who were treated for injuries sustained in a police-reported collision with 448 controls who were matched for age, sex and county residence. Although the prevalence of glaucoma in the crash group was higher than in the control group (7.7% versus 5.6%), glaucoma was not significantly associated with accident involvement (OR = 1.5).

Owsley, McGwin and Ball (1998) estimated odds ratios for the association between injurious and non-injurious motor vehicle crash involvement and visual impairment in a group of 294 licensed drivers of 55 years of age or older. Subjects involved in injurious crashes were 3.6 times more likely to report a diagnosis of glaucoma compared to controls. Glaucoma and reduction of the useful field of view (UFOV, see section 4) were independent predictors of injurious crash involvement. The authors emphasized that glaucoma per se, not visual field sensitivity, was a predictor of crash involvement, suggesting that other characteristics of this pathology elevated crash risk (e.g. medication).
3.4.4 Diabetic Retinopathy (DRP)

Owsley, McGwin and Ball (1998) estimated odds ratios for the association between injurious and non-injurious motor vehicle crash involvement and visual impairment in a group of 294 licensed drivers of 55 years of age or older. They did not observe a significant association between crash involvement and diabetic retinopathy. The OR for diabetic retinopathy was 0.7 for injurious crashes and 1.0 for non-injurious crashes.

Summary

When reviewing the studies on mobility the issue was raised whether peripheral visual field defects put patients more at a disadvantage than central visual field defects. Studies on driving suggest that this assumption may be legitimate as most studies have shown that macular degeneration does not result in increased accident involvement (Szlyk et al., 1993; Szlyk, Pizzimenti et al., 1995; McCloskey et al., 1994) whereas retinitis pigmentosa does (Fishman et al., 1981; Szlyk et al., 1992). Although subjects with macular degeneration do not show increased accident involvement, their driving performance is impaired as reflected in for instance the number of lane boundary crossings or braking response time (Szlyk, Pizzimenti et al., 1995). Szlyk and her colleagues assume that compensatory mechanisms may be at the basis of this discrepancy. Compensatory mechanisms may include reduced risk taking, reduction of speed or self-restricted behavior. Avoidance of driving might be the ultimate way of self-restricted behavior. Studies on self-perceived difficulty report that a large proportion of subjects report to have quit driving, either for visual or non-visual reasons (Szlyk et al., 1997). As noted before, it is likely that vision might have played a role in the decision to quit driving although it is not reported as such.

As for the ocular pathology groups, vision parameters cannot predict accident involvement well (Szlyk et al., 1993; Szlyk, Pizzimenti et al., 1995). Driving performance or perceived difficulty of driving, in contrast, were significantly related to vision parameters, though the proportion of explained variance remains low (Szlyk, Pizzimenti et al., 1995; Szlyk et al., 1997). In the next section, a more complex function is proposed as a predictor of driving performance. It includes a measure of sensory functions such as visual field extent and central vision as well as a measure of higher order functions such as divided and selective attention.

4 From the visual field of view to the useful field of view

Clinical measures, such as visual field extent, might not be predictive of driving performance because they do not take the complexity of the driving task into account. Clinical visual field assessments usually require the detection of stimuli in isolation and call for little attentional demand. Everyday activities, such as driving, on the other hand, “require responses such as localization or identification of suprathreshold targets in cluttered visual scenes as well as the simultaneous use of both foveal and
peripheral vision” (Ball et al., 1988, p. 2210). For example, several subtasks have to be performed while driving, such as keeping track of position on the road, speed and other traffic participants. Meanwhile, the driver has to look for and identify traffic signs and traffic lights amidst a clutter of billboards and neon lights. Moreover, all of these activities have to be performed at a ‘normal’ driving speed. In an attempt to tap this complex ability, Sekuler and Ball (1986) designed a task that measured how well a peripheral target could be localized in the presence of distracters, both with and without a concurrent central task. This test was later termed the useful field of view (UFOV) test. Although the method of the UFOV test varies across studies, the test basically assesses three capacities (Ball & Owsley, 1993): firstly, speed of visual processing, determined by the ability to respond to a peripheral or central target; secondly, divided attention, reflected by the ability to localize a peripheral target while simultaneously performing a central task and thirdly, selective attention, reflected by the ability to perform one or both tasks while the peripheral target is embedded in distracters. The field of view usually extends for 30 degrees eccentrically (radius) and presentation times are usually so short as to preclude eye movements. Many variations in the methods of the UFOV test have been described including the target in the first subtask (a peripheral target or a central target), the central task (faces, X and O’s or cars and trucks), the central task demands (target detection, target identification or discrimination between two targets), duration of target presentation times (90 ms, at 75 or 125 ms or ranging from 40 ms to 240 ms), field of view (15, 26 or 30 degrees eccentricity) and number of distracters (23 or 47). The use of the UFOV as a predictor of driving performance will be discussed in the next sections.

4.1 Population-based studies

Ball and Owsley (1991) developed a model to predict accident frequency as obtained through state records in 53 older drivers. Thirty-two percent of the sample had at least one accident on record. The authors assessed eye health (e.g. ratings on ocular media, diagnosis), visual function (e.g. visual acuity, contrast sensitivity and visual field), mental status (e.g. digit span, verbal memory, comprehension, block design), self reported driving habits and UFOV performance. The UFOV was assessed by three subtests. In the first subtest subjects had to perform a central task only, in the second subtest subjects performed both a central and peripheral task and in the third subtest subjects had to perform both tasks concurrently with distracters in the field. Subjects were then grouped into two groups, based on their scores on the three subtests. Eye health and visual function could not predict accident involvement. In contrast, UFOV and a composite score of mental status accounted for 20% of the accident variance in general and 29% of the variance in intersection accident frequency. Sensitivity and specificity of the UFOV test alone was 92% and 65% respectively.

Ball, Owsley, Sloane, Roenker, and Bruni (1993) report the results of a study on 294 drivers who were recruited from a population of licensed drivers aged 55 years and older. Participants were allocated to one of seven age groups and one of three categories of crash involvement. Eye health (e.g. ratings on ocular media, diagnosis), visual function (e.g. visual acuity, contrast sensitivity and visual field), mental
status (e.g. digit span, verbal memory, comprehension, block design), self reported driving habits and UFOV performance was assessed. The UFOV test consisted of three subtests. In the central discrimination task, the subject had to discriminate two targets that were presented centrally (a car or a truck). The divided attention task consisted of a radial localization task in which the subject had to locate a target (silhouette of a car) while simultaneously performing the central discrimination task. In the selective attention task, the peripheral target was embedded in distracting stimuli. Performance in the UFOV task is a composite score expressed as percent reduction (range 0-90). Using the same predictive model of crash frequency as Ball and Owsley (1991), the authors observed that only UFOV and mental status had a direct effect on crash frequency. UFOV and mental status accounted for 28% of the variance. The size of the UFOV alone had a sensitivity of 89% and a specificity of 81% in predicting crash frequency. Drivers with UFOV reduction greater than 40% were six times (relative risk) more likely to be at least partially responsible for a crash than were those with minimal or no UFOV reduction.

However, some authors (e.g. Schieber, 1994) have remarked that the high sensitivity and specificity values of the UFOV test in the Ball et al. (1993) study were due to the unrealistically high a priori probability of accident involvement. The probability of randomly drawing a driver who had sustained at least one accident was 67%. This probability is much higher than the frequency of accident involvement in the general population. Adjusting the a priori probability of accident involvement will cause a marked drop in sensitivity and specificity values.

The data of the Ball et al. (1993) study should be interpreted with care because the results presented are at least confusing. Data in the table (Table 2, p.3120) do not concur with the numbers that are presented in the Methods sections or with the data as presented in the figure (Figure 2, p. 3114). According to the table, 134 subjects had no crashes whereas in the Methods sections it was reported that only 97 subjects (33% of 294 subjects) were zero-crash drivers. Moreover, according to the table 167 subjects had an UFOV reduction greater than 40% and 127 subject had an UFOV reduction of less than 40%. Inspection of the figure suggests the opposite pattern.

Owsley, McGwin and Ball (1998) estimated odds ratios for the association between injurious and non-injurious motor vehicle crash involvement and visual impairment over a five year period prior to the study. The sample consisted of a group of 294 licensed drivers of 55 years of age or older as reported by Ball and colleagues (1993). Eye health, visual function, mental status, self reported driving habits and UFOV performance were assessed as described before. With regard to non-injurious crash involvement, associations with visual field sensitivity (OR for peripheral area = 1.8, OR for central area = n.s.) and UFOV (OR's ranging from 2.3 to 7.1 as a function of UFOV reduction) were observed. With regard to injurious crashes, the authors observed elevated odds ratios for subjects having an impairment in stereoacuity (OR=2.2), visual field sensitivity (OR for peripheral area = 2.4, OR for central area = 2.6) and UFOV (OR's ranging from 5.5 and 22 as a function of UFOV reduction). Drivers with 40% UFOV reduction were at least 16 times more likely to be involved in an injurious
crash than were those with no or more minor reductions. Drivers with 60% reduction were even 22 times more likely to be involved in an injurious crash.

Owsley, Ball, McGwin, Sloane, Roenker, White and Overley (1998) report the same cohort of 294 drivers as presented in the study by Ball and colleagues (1993). On the basis of a prospective design they evaluated which measures were associated with crash rates during a three-year follow up period. Eye health, visual function, mental status, self reported driving habits and UFOV performance were assessed as described before. Nineteen percent of the drivers incurred at least one crash in the three-year follow-up period. The majority of crashes involved failure to yield right-of-way, failure to heed a stop signal, or misjudged stopping distance. A 40% or greater reduction in the UFOV was associated with a 2.1-times increased risk. Using the UFOV outcome as a continuous variable (rather than using a cut-off point at 40% reduction) yielded a significant linear trend between crash risk and UFOV reduction. Evaluating the three subtests separately, the authors observed that speed of processing and selective attention were not associated with crash involvement. Impaired divided attention, in contrast, was associated with a 2.3-times increased risk.

The results on the association between UFOV and accident involvement were presented as relative risks in the study by Owsley, Ball et al. (1998). The relative risk (RR) is the ratio of the probability of an event (e.g. accident involvement) given a condition (e.g. reduced UFOV) to the probability of an event (e.g. accident involvement) given another condition (e.g. intact UFOV). The RR is equivalent to the OR if, and only if the probability of an event is very low. In the study by Owsley, McGwin and Ball (1998), the probability of accident involvement was not low and hence it is not possible to directly compare the findings to the study of Owsley, McGwin and Ball (1998). It is not possible to compare the studies for a second reason: the same confusion as described when discussing the study by Ball et al. (1993) reoccurs when comparing the two studies. Owsley, Ball et al. (1998) reported that 127 subjects had less than 40% reduction in useful field of view and that 167 subjects had 40% or greater reduction in useful field of view. Owsley, McGwin and Ball (1998), describing the same cohort of drivers, reported the opposite pattern: 167 subjects had less than 40% reduction and 127 subjects had 40% or greater reduction in useful field of view.

4.2 Artificially restricted vision

Wood, Dique and Troutbeck (1994) elaborated on the findings as described by Wood and Troutbeck (1994, section 3.2) and report the effect of field restriction (90 degrees) and monocular viewing (105 degrees) on the UFOV and driving performance. In the UFOV test, cartoon faces were presented centrally and peripherally for a duration of 90 ms. There were two levels of difficulty for the central as well as for the peripheral task. For the low demand central task, subjects had to report whether the central face was present or absent. For the high demand central task, two faces were presented and the subject had to report whether the faces were the same or different. For the low demand peripheral task, subjects were required to locate the target along eight radial directions. In the high demand peripheral task, the target was embedded in distracters. Peripheral field restriction (90 degrees
diameter) resulted in the highest error scores on the peripheral localization task of the UFOV test whereas monocularity had no effect. In accordance with this finding, the authors had observed (see section 3.2) that monocularity had only minimal effect on driving performance whereas a 90 degree field restriction resulted in longer reaction times while driving as measured by the brake response to the illumination of LED’s mounted on the windscreen. Significant correlations between driving performance and contrast sensitivity, mean sensitivity of the visual field and UFOV were observed. The relationship between driving performance and UFOV was only significant in the high demand condition where the subject had to perform a complex central task as well as a complex peripheral task.

Summary
Studies on the UFOV indicate that this test may be a powerful tool to predict driving performance. Approximately 20% of the variance in accident frequency can be accounted for by the UFOV (Ball & Owsley, 1991). Sensitivity and specificity values of respectively 89% and 81% have been reported (Ball et al., 1993). These figures far exceed the values of vision parameters. As reported before, the results as presented by Ball et al. (1993) and subsequent studies reporting results of the same cohort of drivers, should be interpreted with care because the a priori probability of crash-involvement exceeds the probability in the general population and because the data of the Ball et al. (1993) study are at least confusing.

Yet, the higher sensitivity and specificity of the UFOV is not unexpected. The UFOV is presented as a visual attention analyzer, suggesting that a deficit is merely caused by a visual attention problem. But many causes may underlie a reduction of the UFOV. A visual field defect, for example, will result in a failure to detect the target inside a field defect. Likewise, subjects with macular degeneration may perform poorly because they cannot perceive the central stimulus. Or, patients suffering from a generalized slowness after brain lesions may not be able to cope with the short presentation times although divided and selective attention may well be preserved. Ball and colleagues (e.g., Ball et al., 1993), therefore, report that UFOV is a mediating variable between crash frequency on the one hand and eye health, visual function, and mental status on the other. As the UFOV is a mediating variable, encompassing visual and mental health and simultaneously adding attention, it is not entirely unexpected that the percentage of explained variance in driving performance is higher than the percentage of explained variance of the individual underlying factors.

5 Enlarging the field of view by training

Subjects with visual field defects lack some parts of the field of view when fixating. Subjects with central visual field defects cannot perceive objects well within the fixation area whereas subjects with peripheral visual field defects do not notice objects in their periphery. Delayed detection of objects
(cars, cyclists, pedestrians) within the scotomatous area may be hazardous. It is one of the hypotheses of this Ph.D.-thesis that detection of objects can be improved to a (near-) normal level by making use of compensatory viewing behavior. Compensatory viewing behavior consists of eye and head movements to enlarge the field of view in case of peripheral visual field defects. In case of central visual field defects, compensatory viewing behavior consists of eccentric fixation and the use of eye and head movements to assure that no information is concealed by the scotoma. In this chapter studies on training of compensatory viewing strategies and driving in subjects with visual field defects are reviewed.

5.1 Training visual attention and visual scanning

Sekuler and Ball (1986) reported the results of nine older subjects (mean age: 69 years) who practiced a radial localization task during four additional daily sessions. The radial localization task was similar to the UFOV task as described before. It was observed that practice steadily improved peripheral localization. All eccentricities improved to the same extent. Best results were obtained in the most difficult conditions, for example when subjects were required to detect a peripheral target amidst distracters and while simultaneously performing a central task. After three to five weeks, subjects were tested again. Performance on the second assessment did not differ from performance on the last day of practice, suggesting that virtually all the improvement had endured.

Ball, Beard, Roenker, Miller, and Griggs (1988) studied the effect of training on the UFOV (useful field of view) test. The UFOV test is a radial localization task that measures how well a single, randomly positioned target could be localized in the presence of distracters both with and without a secondary center task. Presentation times of the targets are short such that eye movements are precluded. Three levels of distracter number (0, 23, 47) and three levels of center task demand (face(s): present/absent, smile/frown, same/different) were used. Eight young subjects, eight middle-aged subjects and eight older subjects participated in the experiment. Performance on the UFOV was assessed before and after training. Training consisted of five days of practice with feedback. Follow-up examinations were conducted for a period of six months to determine the longevity of improved localization performance. Results indicated that practice produced a general improvement in performance for all age groups and all eccentricities. The three age groups expanded the UFOV by 10 degrees with practice. Follow-up data showed that the improvement in performance persisted over a period of six months.

Ross (1992) examined the effect of a computer-based visual scanning program on a functional task in three subjects with closed head injury. The functional task consisted of a grocery-shelf scanning activity. Each subject stood in front of three shelves, one of which was at eye level, and was asked to remove designated items from the shelves and place them on the counter below. A photograph of the targeted item was placed in the center and at eye-level on one of the shelves. The researcher used an ABA-design. During baseline assessment (A), speed, accuracy, and referencing glances (looking back to the photograph before identification of the target) were collected for the functional task for at least five assessments. During intervention (B), subjects were trained to use scanning eye movements in a
pattern similar to that used in reading (i.e., left to right across rows, top to bottom). Time and accuracy were assessed for this scanning task. Functional performance was also assessed during the intervention phase. The intervention phase consisted of six to nine sessions of 15 to 30 minutes each. During the second baseline (A) assessment, measures of the functional task were collected when the visual training was stopped. The author observed that learning occurred throughout the study on both the shelf-scanning and computer visual scanning tasks but that treatment did not affect performance in scanning time on the functional task more than could be expected from the naturally occurring practice effect. She further observed that learning proceeded faster for some measures (e.g., scanning time or accuracy) of the shelf-scanning task and for other areas of the computer tasks and suggested that learning was not interrelated or codependent. The author therefore concluded that the computer-based visual scanning program may not be an appropriate modality for achievement of a functional therapy outcome.

Zihl (1995) investigated the effect of training in fourteen patients with homonymous hemianopia. They all showed impaired visual scanning before training, as characterized by significantly longer search times and high rates of repetition of scanpath and of fixations. Visual scanning was assessed by means of a dot counting task. The task consisted of 20 white dots randomly scattered over the screen. Subjects were instructed to count the dots while eye movements were monitored. Training consisted of two phases. In the first phase, patients were trained to make large saccadic eye movements to obtain a quick view of the hemispace. In the second phase, the spatial organization of the oculomotor pattern of searching was trained. Subjects viewed large stimulus arrays (52° x 45°) and were asked to search for targets. Before responding, they were instructed to glance over the whole projection screen from left to right to orient themselves within the stimulus array. Subjects were instructed to use eye movements and were never allowed to make head movements. Training was ended when the patients’ performance was in the range of the patients with normal scanning pattern. The number of training sessions varied between 8 and 23, with a mean of 16 sessions. After training, performance on the dot counting task improved significantly. Visual scanning was better organized and contained fewer saccades and fixations than before practice. Consequently, search times were markedly decreased. After training, 11 out of 14 patients showed search times that fell within the normal range. Moreover, the number of complaints in everyday life decreased after training. The author therefore concluded that specific practice with the spatial organization of visual search can improve the quality of compensation and can reduce the degree of the patient’s visual disability in real life.

Seagull and Gopher (1997) trained pilots of a helicopter to increase head movements in order to enlarge the field of view. Pilots using a single-eye helmet-mounted display for night vision experience problems with a limited field of view and the lack of binocular information. The use of the helmet is further complicated by the fact that it is difficult for a pilot to identify the sources of motion and change represented on the helmet display. Movements of the images on the helmet can be caused by several factors, such as a change in the pilot’s head position. This has led many pilots to deliberately limit their head motion to avoid disorientation and confusion. Thus, pilots tend to avoid head movements
whereas head movements are necessary to scan the environment. The study aimed at increasing head movements by exposing pilots to a secondary task that required them to move their heads while flying a simulated helicopter through a winding canyon display. The secondary task required that they detected targets presented at random distances from the flight path. Training consisted of 120 minutes of in-the-air flight time. It was observed that the experimental groups increased the rate and magnitude of their head movements even when the secondary task was eliminated. The increase was observed when they wore the helmet as well as during normal viewing. In contrast, with practice the control groups reduced their head movements when wearing the helmet and no change was observed in their head movements under normal viewing conditions. The improved visual scanning ability of the experimental group resulted in a larger number of completed flights, longer flight duration in incomplete flights, and a higher rate of improvement with training. This study therefore clearly suggests that relatively short but directed training was highly effective in reshaping basic scanning behavior and improving performance in a complex, dynamic visual environment.

Nelles, Esser, Eckstein, Tiede, Gerhard, and Diener (2001) reported the effect of visual scanning training in twenty-one patients with homonymous hemianopia. Patients were sitting in front of a large screen (1.25m x 3.05m at a distance of 1.5m) on which forty red lights were positioned. Detection of a visual stimulus and reaction times were monitored before and after training. Training aimed at improving the use of exploratory eye movements without head movements during eight session of 30 minutes each. Subjects were instructed to systematically scan the board horizontally (row by row). After training, detection of and reaction to visual stimuli with use of exploratory eye movements improved and this improvement maintained at follow up 8 months later. No effects were observed when subjects were required to fixate a central stimulus, suggesting that the training contributed to a compensation of hemianopia without restitution of the visual fields. Results on the ADL questionnaire (including activities such as bumping into obstacles, finding objects in room, crossing streets and reading) demonstrated that subjects reported less problems with these activities after training than before training.

**Summary**

Most studies on training of compensatory scanning techniques are focussed on subjects with visual field defects due to brain damage. These studies clearly suggest that compensatory viewing behavior can be taught by training visual attention, eye or head movements (Nelles et al., 2001; Zihl, 1995). Training methods to enlarge the field of view in visually healthy subjects by visual attention or head movements have also been reported to be successful. (Ball et al., 1988; Seagull & Gopher, 1997). Most studies also describe subjective reports of transfer to tasks that were not trained.
5.2 Driving related training

5.2.1 Expansion of the UFOV

Ball (1997) reported preliminary evidence that expansion of the UFOV improves driving performance. She reported the results of 68 drivers of 55 years of age or older. Thirty-three of these subjects completed a UFOV training program, 24 completed a simulator training program, and 11 served as controls. Subjects in the UFOV training received individualized training until a UFOV size of less than 30% loss was achieved. Subjects in the simulator training received three hours of training in a driving simulator and one additional hour in an open road demonstration of the skills discussed while in the simulator. Control subjects received no training. The results of UFOV training were successful in that those in the UFOV training showed a significant decrease in UFOV loss. UFOV size did not change significantly for those in the simulator or control groups. A complex reaction time task did also reveal a significant improvement for the UFOV group only. With regard to driving, a significant improvement in global ratings of their driving skills was observed for all groups. Driving skills were evaluated by an experienced driving instructor and two evaluators who were sitting at the back seat. Six driving related composite scores also showed significant improvement after training regardless of group. Yet, only for the UFOV training group, the number of hazardous maneuvers during the driving test was significantly (50%) reduced. The author therefore concluded that UFOV training transfers to driving tasks, such as reduced stopping time to an unexpected perceptual event and to a reduction in the number of dangerous maneuvers in an on-road driving test.

5.2.2 Low vision devices

Most training programs to improve driving performance in low vision patients make use of low vision devices (such as bioptic telescopes or amorphic lenses) to enhance vision. Telescopes are used for magnifying distant objects in patients with reduced visual acuity. Bioptic telescope systems are miniature telescopes mounted into an individual's regular spectacle lenses (carrier lens), positioned above or below what is the direct line of sight as the individual is facing forward. The advantage in this arrangement is that it allows the user to look through the telescopic portion for spotting and magnifying distant objects while permitting a rapid change in fixation to the larger carrier lens for general viewing of the entire visual field. The transition from one lens to another may be made as rapidly as the patient is able to move his eyes and head. The most commonly used magnification for driving are 2.2X, 3.0X and 4.0X bioptic telescopes (Kelleher, 1979; Szlyk et al., 2000). Amorphic lenses are usually prescribed to subjects with peripheral field restrictions. These lenses minify the image along the horizontal meridian while maintaining the same size along the vertical meridian. This minification enables the patients to view a wider field, which is necessary for safe navigation of the environment. The power of the minification ranges from -1.2X to -2.0X (Laderman et al., 2000).

Both low vision devices have disadvantages. Users of bioptic telescopes experience reduced fields of view and report the presence of a ring scotoma, resulting from the housing of the telescope. Patients looking continuously through amorphic lenses may complain of distortion, nausea, and dizziness.
caused by the horizontal minification of the lenses and off-axis rotation of the image. Yet, these disadvantages may be eliminated by using the low vision devices as spotting tools. Effective use of the bioptic telescope and amorphic lenses requires training. In the next paragraphs, some studies are reported that investigated the effect of training the use of low vision devices in relation to driving.

Huss (2000) reported the effects of a low vision driver education training in 47 subjects with reduced visual acuity (range: 0.1-0.4). Training consisted of approximately 40 hours of classroom driver education instruction, an additional 30 hours of vision utilization training as a passenger in a vehicle (with and without the use of low vision aids), and approximately 50 hours of actual on-road driving under the auspices of a certified driver rehabilitation specialist. Training lasted six to eight weeks. Driving performance was weekly assessed by means of a standardized 64 km test route. Of the 47 subjects, 32 were afforded the opportunity to undergo comprehensive driver license testing. All of them became legally licensed to drive. Restrictions were applied on a case-by-case basis by the Division of Motor Vehicles and included such driving restrictions as: daytime driving only, 80 km radius driving, use of bioptics, or no interstate driving. A telephone survey with each of the trainees at the end of the research project revealed that 14 subjects had accident and violation free driving records, that seven subjects had caused eight minor traffic violations, and that 12 subjects were involved in 18 accidents (but they were not at fault in ten of those accidents). After 10 years of experience with the low vision driver education training program Huss reported that individuals who completed low vision driver education satisfactorily performed at a level comparable to their normally sighted counterparts in terms of basic visual skills and demonstrated above average skills in vehicle handling and ability to react to traffic hazards.

Szlyk, Seiple, Laderman, Kelsch, Stelmack, & McMahon (2000) evaluated a vision rehabilitation program aimed at improving mobility and driving in persons with central vision loss. The training group received bioptic telescopes and training. Emphasis of the training was on the use of the bioptic telescope as a spotting device; that is, to spend the majority of time in the carrier lens with brief and frequent glances into the bioptic lenses. To accomplish this, subjects were trained to locate objects, track stimuli, to increase scanning, and to enhance visual memory. These activities were trained during an orientation and mobility training as well as while driving. Training consisted of 13 weekly sessions. Subjects in the no-training group were given bioptic telescopes but without any training. Before and after training, a functional assessment and a driving skills assessment were carried out. The functional assessment consisted of tasks of recognition (e.g., reading signs), mobility (e.g., navigating common public areas), peripheral identification (e.g., naming objects presented in the periphery), scanning (e.g., counting the number of randomly placed white cups in a testing room within 15 seconds), tracking (e.g., tracing an irregular line), and visual memory (e.g., recalling objects presented on a slide). The driving skills assessment consisted of a driving simulator test and an on-road driving test. Recognition (e.g., braking response times to stop signs), mobility (e.g., simulator accidents), peripheral identification (e.g., number of lane boundary crossings), scanning (e.g., number of eye movements), and visual memory (e.g., reporting the current speed limit) were assessed. After
training, there was improvement in all the visual skills categories beyond a test-retest reliability. Most improvement was reported for tasks related to scanning. The least improvement was reported for tasks related to peripheral identification. The improvement did not change from the first post training assessment to the second post training assessment (three months later). The untrained group showed improvement in all of the visual skills categories, as well. But the trained group showed significantly greater improvement compared to the untrained group for tasks involving recognition, peripheral identification, and scanning. Moreover, when the driving-related skills were analyzed separately, there was a significant difference between the trained and untrained groups. The authors therefore concluded that training would be recommended for effective use of the bioptic lenses, especially for use in driving.

_Laderman, Szlyk, Kelsch, and Seiple (2000)_ described a training program for the effective use of bioptic amorphic lenses in 15 subjects with retinitis pigmentosa, choroideremia, or Usher’s syndrome (type II). Peripheral detection, recognition, scanning, tracking, visual memory and mobility were assessed and trained as described above. Results as described by Szlyk, Seiple, et al. (1998) showed an overall 37 percent improvement in the visual tasks. Patients showed 39% improvement in tasks involving peripheral detection, 41% improvement in recognition tasks, 27% improvement in scanning tasks, 36% improvement in visual memory tasks, and 46% improvement in mobility tasks. The greatest area of improvement was in the area of mobility. The amorphic lenses helped patients to immediately detect something in their periphery by glancing into the amorphic lenses. This increased the patients’ ability to navigate their environment safely and independently, and helped them gain confidence during driving training sessions. Eighty-six percent of the patients stated that, if it were legal to do so, they would definitely use the amorphic lenses for driving.

**Summary**

The studies that were described above focussed on subjects with visual field defects due to ocular pathology and made use of optical devices to enhance vision. Improving driving related skills by means of improving compensatory viewing behavior was successful in all of the abovementioned studies. Yet, more detailed information is required on the driving performance scores before and after training. Did subjects pass a driving test after training? Is accident involvement after training comparable to accident involvement of a control group? These questions were not answered by the studies and merely suggest that driving can be improved by means of improving compensatory viewing behavior.

6 **Conclusion**

In the preceding paragraphs, studies investigating the relationship between vision on the one hand and mobility and driving performance on the other hand were briefly reviewed. It can be concluded
that mobility performance of low vision patients could be predicted moderately well. Contrast sensitivity and visual field were the most commonly cited predictors whereas visual acuity did not play a significant role in predicting mobility performance. The findings on driving performance were in accordance with the findings on mobility. Visual acuity was either not associated with driving performance or only weakly. Visual field, in contrast, was related to driving performance. Severe visual field defects such as hemianopia or severe field restrictions were reported to lead to poor driving performance whereas less severe visual field defects were characterized by slower but otherwise safe driving performance. Despite the relationship between the visual field and driving performance, its value as a predictor was low. The low predictive power of the visual field could be caused by the difference in complexity between a visual field assessment and the use of the visual field while driving. Alternatively, it has been argued that the predictive power of vision parameters might be reduced by compensatory behavior such as slowing down, self-restricted behavior, reduced risk-taking or compensatory viewing mechanisms.

References


Bibliography and references of section I: Visual fields


