ANGLIA RUSKIN UNIVERSITY

FACULTY OF SCIENCE AND TECHNOLOGY

TOWARDS A FUNCTIONAL VISUAL FIELD ASSESSMENT FOR LOW VISION

HIKMAT SUBHI

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Abstract

Visual field assessment is not only important to monitor disease progression, but also to reflect and predict functional difficulty in the real world. Despite this, no test currently available is optimised for determining functional consequences of visual field loss. The aim of this study is to determine the locations within the visual field that best reflect functional difficulty, and to use this information to develop an appropriate method of assessing field loss which reflects its functional consequences.

For the first experiment, fifty two participants with peripheral field loss undertook binocular assessment of visual fields using the 30-2 and 60-4 SITA Fast programs on the Humphrey Field Analyser. The mean threshold within different areas of the visual field was used as the main outcome measure. Self-reported difficulties with activities of daily living were assessed using the Dutch ICF Activity Inventory. Greater visual field loss was associated with greater perceived difficulty, and both central (0-30 deg) and peripheral (30-60 deg) visual field areas were similarly related to self-reported function. The results of this experiment suggested that in order to accurately determine the functional consequences of visual field loss, it is necessary to consider the visual field beyond 30 degrees.

These findings informed the development of custom visual field assessments in Experiment 2. Fifty participants with peripheral field impairment undertook three custom binocular visual field tests on the Octopus 900 that assessed the field out to 60 degrees from fixation: a threshold, 10dB supra-threshold, and a 10dB kinetic assessment. The mean threshold, percentage of stimuli seen, and visual field area were used as the main outcome measures for analysis. Visual field scores were compared to overall self-reported function assessed during the Dutch ICF Activity Inventory, and mobility function assessed using the Independent Mobility Questionnaire. Results were also compared to currently available methods of assessing functional visual field including integrated visual fields, and Esterman tests.

Perceived function related similarly to binocular threshold, suprathreshold, kinetic, and Esterman visual field scores suggesting that as long as a functional visual field test is performed binocularly and includes assessment of eccentricities to 60 degrees, the paradigm used to assess the visual field makes little difference to the test's ability to predict function. Quick tests using a kinetic or suprathreshold paradigm are more favoured by patients however. A binocular visual field assessment that utilises a suprathreshold or kinetic paradigm, and that assesses the visual field past 30 degrees is effective at reflecting the functional abilities of patients with peripheral visual impairment.

Keywords: visual impairment, visual field, visual function, self-report, mobility function

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Abbreviations

AAP	Adelaide Activities Profile
ADL	Activities of daily living
AMA	American Medical Association
AMD	Age related macula degeneration
AUC	Area under the curve
BRAO	Branch retinal artery occlusion
CPS	Critical print size
CS	Contrast sensitivity
CVI	Certificate of Vision Impairment
D-AI	Dutch ICF Activity Inventory
dB	Decibels
deg	Degree
ETDRS	Early treatment diabetic retinopathy study
FES-I	Falls Efficacy Scale-International
FFS	Functional field score
HFA	Humphrey Field Analyser
ICF	International classification of functioning
IMQ	Independent Mobility Questionnaire
IVF	Integrated visual fields
NEI-VFQ	National Eye Institute- Visual Function Questionnaire
PRoFouND.	The Prevention of Falls Network for Dissemination
ROC	Receiver operator characteristics
RP	Retinitis pigmentosa
VA	Visual acuity
WHO	World Health Organization
wpm	Words per minute

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Copyright Declaration

Chapter 1

Visual Fields in Low Vision

1.1 Visual impairment

Visual impairment or low vision is a reduction in vision that cannot be corrected with glasses or contact lenses that reduces an individual's ability to function (World Health Organization, 2007). Hereditary retinal disorders including retinitis pigmentosa are the leading cause of sight loss certification in England and Wales in the working population (Liew et al., 2014). Other major causes of visual impairment in the developed world include age related macular degeneration (Evans & Wormald, 1996; Evans, 1998), cataracts, glaucoma, and diabetic retinopathy (Foster & Johnson, 1990; Wormald et al., 1992; Gieser & Schein, 1993).

1.2 Peripheral visual field loss

Whilst macular degeneration results predominantly in loss of central function, visual impairment can involve the loss of the peripheral visual field, resulting from conditions including glaucoma, retinitis pigmentosa (RP), and neurological incidents resulting from strokes, tumours, and trauma.

Glaucomatous visual field loss varies with the stage of the disease. Typically, early change in the visual field manifests as small areas of focal loss in the paracentral visual field, most commonly in the superior nasal aspect of the field (Figure 1.1). As the disease progresses, an enlargement of these paracentral scotomas can lead to the formation of arcuate loss. Arcuate defects are most commonly found in the superior hemifield. Large arcuate scotomas may form in the superior and inferior visual fields in advanced untreated disease. This can lead to the formation of a ring scotoma (Cubbidge, 2005; Broadway, 2012). Glaucomatous visual field loss usually starts monocularly, and whilst a binocular condition, progresses asymmetrically.

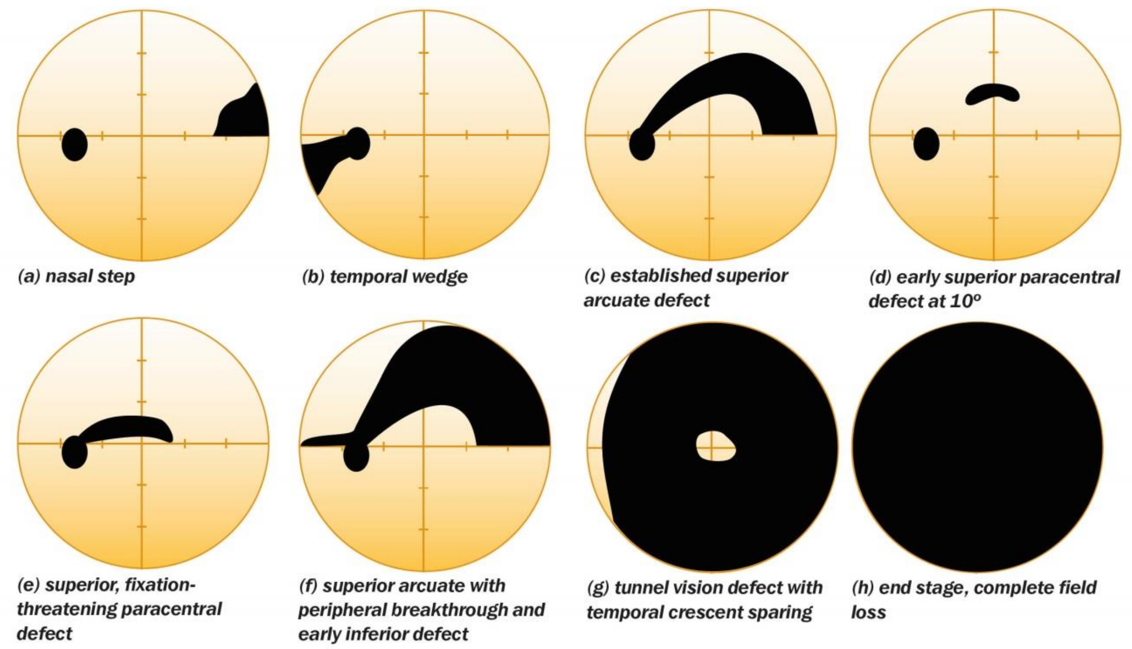


Figure 1.1 Glaucomatous visual field defects in the left eye. Taken from Broadway (2012).

There are different patterns of visual field loss in RP. Although patients often exhibit concentric loss of the visual field in later stages of the disease, visual field loss may begin as focal restriction in the nasal region which can progress to form perimacular, paramacular, midperipheral arcuate, or ring defects (Figure 1.2). Unlike glaucoma, RP usually affects both eyes similarly.

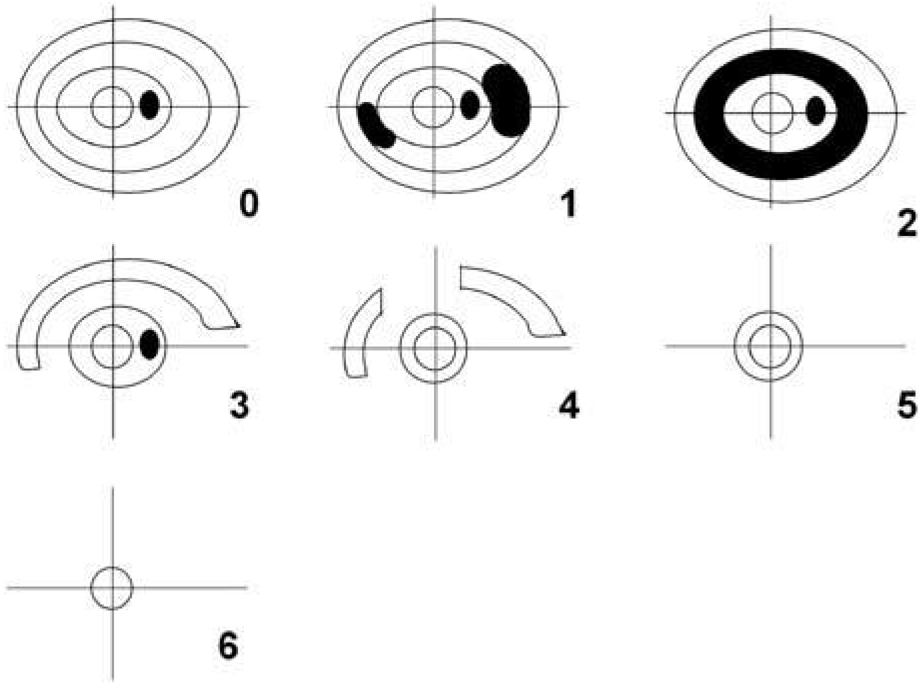


Figure 1.2 Classification of visual field defects in the right eye in retinitis pigmentosa. Taken from Sugawara et al., (2009).

Other causes of peripheral visual field loss include lesions in the neurological pathway (Figure 1.3). Pituary tumours for example can give rise to a bitemporal hemianopia. Bilateral homonymous defects arise from post-chiasmal lesions of the neurological pathway, including as a result of a stroke.

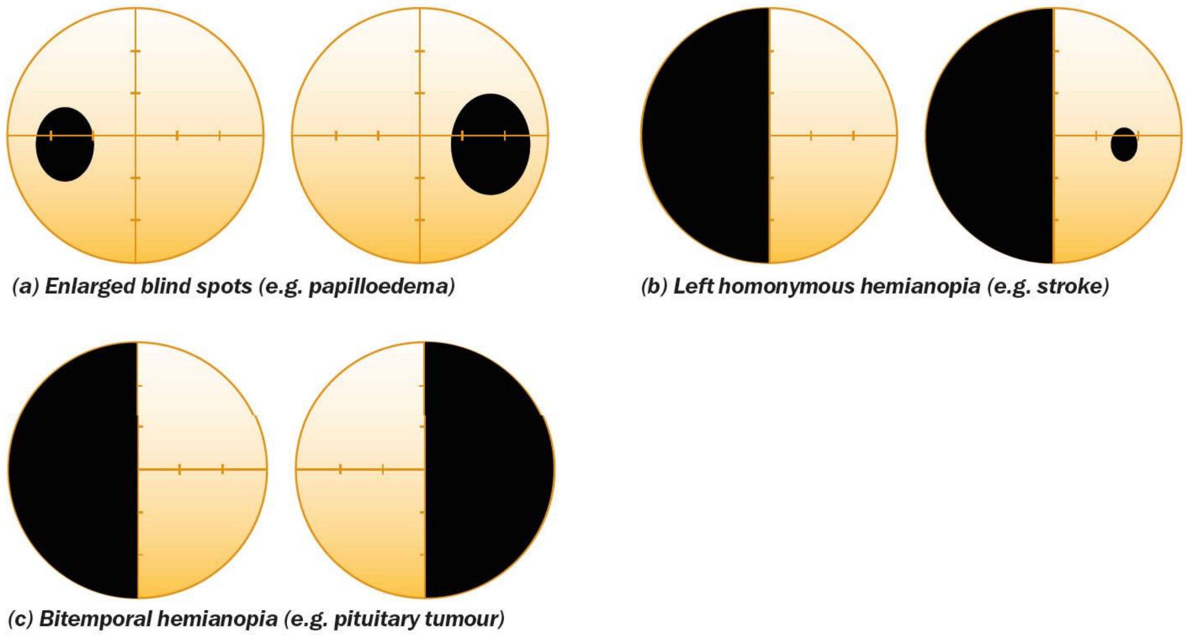


Figure 1.3 Neurological visual field defects. Adapted from Broadway (2012).

1.3 Sight loss registration

The process of registering a patient in the UK as visually impaired requires completion of a Certificate of Vision Impairment (CVI) by a consultant ophthalmologist. The CVI formally certifies someone as sight impaired or as severely sight impaired to ensure services are accessible as appropriate. Two groups of sight loss registration exist: patients may be registered as being either severely sight impaired or sight impaired based on the extent of loss of the patient's visual acuity and visual field. Local authorities in the UK are required to maintain a register of sight-impaired and severely sight-impaired adults living in its area. Those who have a CVI can choose whether to be included in their local authority's register (Table 1.1).

To be registered as severely sight impaired (SSI) sight has to fall into one of the following categories while wearing refractive correction as needed:
▪ Visual acuity below 3/60 with a full visual field ▪ Visual acuities better than 3/60 but below 6/60 with a very contracted field of vision ▪ Visual acuity of 6/60 and above but with a contracted field of vision especially if the contraction is in the lower part of the field
To be registered as sight impaired (SI) sight has to fall into one of the following categories while wearing refractive correction as needed:
▪ Visual acuity better than 3/60 but below 6/60 with a full visual field ▪ Visual acuity below 6/24 but with moderate contraction of the field, opacities in media or aphakia ▪ Visual acuity of 6/18 or better but with a gross visual field defect, for example hemianopia, or marked contraction of the visual field, for example in retinitis pigmentosa or glaucoma.

Table 1.1 Definitions of sight impairment (SI) and severe sight impairment (SSI) (Department of Health, 2013).

Sight loss registration initiates access to a range of support services that facilitate independent living and continued employment (Department of Health, 2013). It has been estimated however that a large proportion of patients eligible for registration remain unregistered (King et al., 2000; Barry & Murray, 2005), in particular patients exhibiting visual field loss alone rather than visual acuity loss (Bunce et al., 1998; King et al., 2000; Barry & Murray, 2005). Studies also suggest that patients with permanent visual loss receiving treatment (e.g. glaucoma) are less likely to be registered than patients with untreatable disease (e.g. RP) (Robinson et al., 1994; Bunce et al., 1998; King et al., 2000; Barry & Murray, 2005). Guerin et al., (2014) evaluated consistency among ophthalmologists in visual impairment registration of glaucoma patients with significant field loss, and found that there is very poor agreement with regards to eligibility. They suggest current visual field criteria are open to significant subjective interpretation, with imprecisely defined categories such as “very contracted” and “gross defect” (Department of Health, 2013), and propose more objective criteria need to be introduced.

1.4 Strategies of visual field assessment

Perimetry is the assessment of an individual's visual field and involves the estimation of contrast sensitivity throughout the field. The examination of the visual field can be accomplished by two methods: kinetic or static perimetry.

The hill of vision is a representation of retinal sensitivity (Figure 1.4). It demonstrates the extent of the visual field, and retinal sensitivity throughout the visual field. Retinal sensitivity is highest at fixation and decreases with increasing eccentricity.

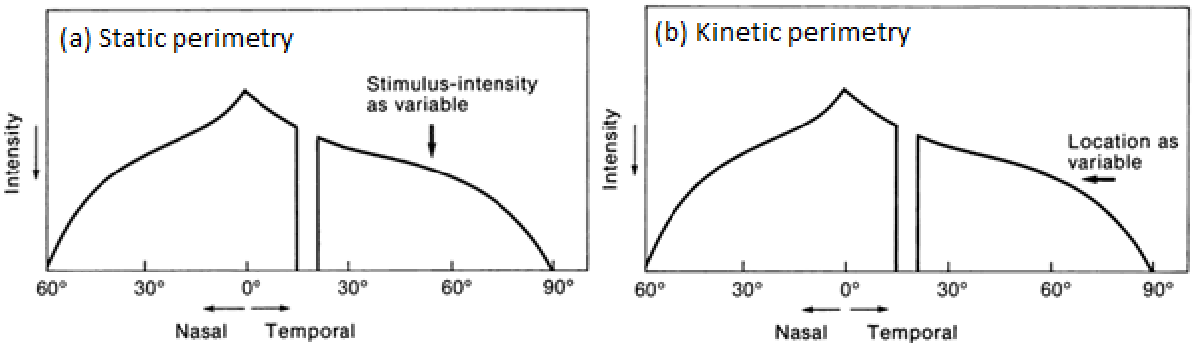


Figure 1.4 The hill of vision representation of the visual field of the right eye (Hattington & Drake, 1990).

Kinetic perimetry (Figure 1.4a) involves moving a stimulus of set intensity from less sensitive to more sensitive areas and recording the location in the field the stimulus is seen. The same stimulus is presented at other positions in the visual field, enabling the practitioner to connect the points in the visual field where the stimuli are seen, forming an isopter. Isopters indicate regions of the same contrast sensitivity in the visual field. A more comprehensive kinetic examination of the field may include using stimuli with different intensities to map out several isopters. Locations marked as not seen in initial examination can be rechecked with increasing stimulus intensity. Traditional Goldmann kinetic perimetry is a manual examination that requires examiners that are well trained, and produces results that are dependent on the examiner's judgement. Automated perimetry eliminates this examiner dependence, and while no standard automated kinetic examination exists, semi-automated kinetic perimetry is available on several widely used perimeters including the Humphrey Field Analyser (Carl Zeiss Meditec, Inc., Dublin, CA), and the Octopus 900 (Haag-Streit International, AG, Koniz, Switzerland). Kinetic perimetry can rapidly define areas of visual field with deep focal loss, and remains the fastest method for delineating the extent of the visual field. One limitation of kinetic perimetry is the effect of the patient's reaction time on the position of the isopter, although more accurate estimations of response times, and constant target speeds are now possible with semi-automated kinetic perimetry.

In static perimetry (Figure 1.4b) stimuli are presented at the same location and their detection is recorded. Typically, automated static perimetry uses constant stimulus sizes and durations. Locations of the stimuli are usually predefined in set test patterns. A commonly used test pattern is the 24-2 on the HFA (Figure 1.5).

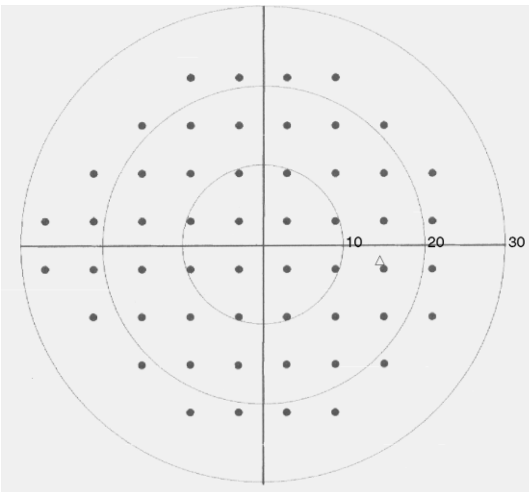


Figure 1.5 The central 24-2 threshold test pattern for the right eye (HFA Manual).

In static threshold perimetry stimulus contrasts are varied to determine the threshold of contrast detection, whereas static suprathreshold assessment offers a rapid examination of a large number of test locations in the visual field by presenting a single stimulus of a contrast expected to be seen at each point. Since it is known that there is a decline in sensitivity of the field with increasing eccentricity from the fovea however, small relative defects near the fovea could be missed with suprathreshold examination if the assessment is not gradient adapted.

In threshold perimetry, adaptive staircase procedures, where the intensity of stimulus presentation is dependent on previous responses (Falmagne, 1986; Treutwein, 1995) have reduced the test time of threshold assessments. Various adaptive procedures exist on different perimeters, for example Swedish interactive thresholding algorithm (SITA) Fast on the HFA, and tendency oriented perimetry (TOP) on the Octopus 900.

1.5 Effect of binocular visual field loss on visual activities

A visual impairment is a loss of visual function reflecting a structural problem with the visual system. This impairment can result in difficulty encountered in undertaking tasks, or activity limitations. A participation restriction is a problem experienced in involvement in life situations (World Health Organization, 2013). There are a large number of instruments and assessments used to identify areas of reduced function, and these are discussed in Chapter 2.

Visual acuity alone may be inadequate indicator of the degree of visual impairment (Genensky, 1976; Cullinan, 1978), and it is reported that visual impairment defined by visual acuity is not the only dimension of the association with subjective disability, and additional vision function measures are required to understand the impact of vision loss on everyday life (Rubin et al., 2001). Visual field loss is also recognised as detrimental to function by its inclusion in visual impairment registration criteria, where moderate and severe field loss are specified in sight impaired and severely sight impaired registration criteria (Department of Health, 2013).

Visual field loss is commonly associated with difficulty in activities of daily living in several areas with key issues as outlined in the categories below.

1.5.1 Mobility

Although assessment of visual acuity is necessary to determine difficulty with certain activities such as reading fine print, it is only weakly associated with the ability to see large low contrast objects or to navigate safely and independently in unfamiliar environments (Marron & Bailey, 1982; Brown et al., 1986). Furthermore, while previous studies have found that visual acuity, visual fields and contrast sensitivity all correlate with mobility performance, visual field and contrast sensitivity are stronger predictors than acuity (Marron & Bailey, 1982; Bailey et al., 1993; Kuyk et al., 1998; Hassan et al., 2002). Other studies suggest that the visual field is a better predictor of mobility than both visual acuity and contrast sensitivity (Lovie-Kitchin et al., 1990; Tabrett & Latham, 2011). Even in a sample of participants with central vision loss due to AMD, it has been suggested that mobility variables can be predicted from measures of vision acuity and the visual field (Brown et al., 1986).

Many studies that attempt to relate visual field loss to self-reported function or performance use monocular assessments of the visual field (Marron & Bailey, 1982; Szlyk et al., 1997; 1998; Geruschat et al., 1998; Nelson et al., 1999; Rubin et al., 2001; Varma et al., 2006; Ringsdorf et al., 2006; Seo et al., 2009; Sugawara et al., 2009). The visual fields in these studies have been assessed using threshold (Nelson et al., 1999; Varma et al., 2006; Ringsdorf et al., 2006), suprathreshold (Rubin et al., 2001), and kinetic paradigms (Marron & Bailey, 1982; Szlyk et al., 1997; Geruschat et al., 1998; Seo et al., 2009; Sugawara et al., 2009), and have been found to reflect self-reported mobility function (Szlyk et al., 1997; Geruschat et al., 1998; Nelson et al., 1999; Rubin et al., 2001; Varma et al., 2006; Ringsdorf et al., 2006; Seo et al., 2009; Sugawara et al., 2009) and actual performance (Marron & Bailey, 1982) in patients with glaucoma (Nelson et al., 1999; Ringsdorf et al., 2006), RP (Szlyk et al., 1997; Geruschat et al., 1998; Sugawara et al., 2009; Seo et al., 2009), in samples of elderly individuals (Rubin et al., 2001; Varma et al., 2006), and mixed low vision patients (Marron & Bailey, 1982).

Other studies report an association between binocular visual field loss and self-reported mobility function (Mills & Drance, 1986; Viswanathan et al., 1999; Bibby et al., 2007). Perceived difficulty in avoiding bumping into, or tripping over obstacles was found to correlate with binocular visual field loss in a study by Mills & Drance (1986). Viswanathan et al., (1999) also found that binocular visual field loss correlated to responses to questions relating to bumping into things and navigating stairs. In another study, Bibby et al., (2007) report that the binocular visual field correlated significantly with self-reported mobility function. Nelson et al., (2003) found that self-reported difficulties with dark adaptation and disability glare, and activities demanding functional peripheral vision such as avoiding tripping over and bumping into objects were found to be significantly associated with the severity of binocular visual field loss in a group of glaucoma patients with severe field loss.

Reduced assessed mobility performance is also associated with binocular visual field loss (Haymes et al., 1996; Turano et al., 1999; Lovie-Kitchin et al., 1990; Turano et al., 2004; Hassan et al., 2007; Lovie-Kitchin et al., 2010; Timmis & Pardhan, 2012). Increased field loss relates to increased likelihood of tripping over obstacles and collisions with pedestrians (Lovie-

Kitchin et al., 1990; Turano et al., 1999; Haymes et al., 2002; Lovie-Kitchin et al., 2010; Lisboa et al., 2013). Glaucomatous visual field loss is associated with slower walking speeds and a greater frequency of stumbles on a mobility course when compared with normally sighted individuals (Turano et al., 1999). Slower walking speeds and orientation errors on a mobility course have also been reported in samples of mixed low vision patients with binocular visual field loss (Lovie-Kitchin et al., 1990; 2010). Similarly, in a sample of patients with RP, Haymes et al., (1996) reported reduced assessed mobility performance on three real world mobility routes with greater binocular field loss. Turano et al., (2004) demonstrated that loss of the binocular visual field in elderly adults is also associated with a decline in mobility performance. They report that walking speed decreases, and the number of bumps into obstacles increases with loss in the binocular visual field in a large sample of elderly adults. In another study, latency in walk initiation, slower walking speed, and frequency of obstacle contacts were associated with binocular visual field restriction, simulated using a head mounted display, of normally sighted individuals (Hassan et al., 2007).

1.5.2 Increased risk of falling

Visual field loss has been reported to be associated with increased likelihood of falling (Marron & Bailey, 1982; Brown et al., 1986; Lovie-Kitchin et al., 1990; Haymes et al., 1996; Black et al., 1997; Geruschat et al., 1998; Kuyk et al., 1998; Klein et al., 1998; Turano et al., 1999; Ramrattan et al., 2001; Klein et al., 2003). Ramrattan et al., (2001) report that individuals with bilateral visual field loss were more likely to use a walking aid, and be involved in frequent falls. Studies have shown that people with worse visual fields are at an increased risk of falling due to worse postural stability (Fernie et al., 1982; Turano et al., 1993; Maki et al., 1994; Lord et al., 1994; Shabana et al., 2005). The visual system plays a vital role in retaining balance while standing still and while moving (Freeman et al., 2007), and poor balance has been associated with falls, and falls with injury (Maki et al., 1994; Vellas et al., 1997). Turano et al., (2004) have shown that peripheral visual loss is associated with increased risk of tripping over obstacles, independent of age, gender and race, and Freeman et al., (2007) found that falling was associated with binocular visual field loss but not with presenting visual acuity, contrast sensitivity or stereoacuity. The risk of falls, and of falls with injury, has been shown to increase as the severity of visual field impairment worsens (Patino et al., 2010). Freeman et al., (2007) evaluated the visual field binocularly from merged monocular fields (Crabb et al., 1998) and investigated the effect of visual field loss on the risk of falls in older adults. They found worse visual field scores were associated with an increased risk of falling. After adjusting for demographic health variables, the only vision variable associated with falling was the binocular visual field.

Other studies have not found an association between the visual field and fall history (Glynn et al., 1991; Friedman et al., 2002), possibly due to poor recall of fall occurrence. Cummings et al., (1988) found a weak relationship between the number of documented falls and the number of falls patients recall, and concluded that falls among the elderly population are often forgotten. Other predictors of falling have been suggested in the literature. One of these predictors is the fear of falling, and the relationship between fall frequency and the fear of falling is well documented (Howland et al., 1993; Tinetti et al., 1994; Arfken et al., 1994; Fessel and Nevitt, 1997; Howland et al., 1998; Lachman et al., 1998). Some studies have used a single questionnaire item to determine fear of falling (Afken et al., 1994; Franzoni et al., 1994; ; Liddle & Gilleard, 1995; Vellas et al., 1987; Howland et al., 1998), although it is suggested that self-perception of global traits like fear are poor predictors of actual behaviour (Mischel, 1968). Expanding from a rudimentary dichotomous single item measure to a continuous measure allows the discrimination between different levels of fear and enables the assessment of fear of falling in different activities (Yardly et al., 2005). Falls related self-efficacy questionnaires have shown to correlate with single item measures of fear of falling, and to predict decline in activities of daily living (Tinetti et al., 1990; Tinetti et al., 1994; Hill et al., 1996; Mendes de Leon et al., 1996; Myers et al., 1996).

Fall history and the fear of falling have been shown to relate to activity restriction (Vellas et al., 1987; Howland et al.,1998; Yardly et al., 2002; Delbaere et al., 2004), and in particular to reduced participation in social activities (Tinetti et al., 1994; Cumming et al., 2000). There is a relationship between activity participation and falls and fear of falling, but the direction of cause and effect is unclear. Lamoureux et al., (2010) assessed a range of clinical function and demographic variables of a sample of individuals with low vision and found that only non-participation in physical activity was independently and significantly associated with falls. Others have reported similar findings (Tinettii et al., 1988; Gregg et al., 2000; Gillespie et al., 2001).

1.5.3 Reading

Visual field loss, independent of visual acuity, is associated with a diminished reading performance (Ramrattan et al., 2001). More specifically, Burton et al., (2015) report that loss in the inferior left region of the visual field may be important for changing lines during reading in a sample of 58 patients with glaucoma. They assessed the visual field using the IVF method, and used reading speed as an indicator of reading ability. In their sample of 100 mixed low vision participants, Tabrett & Latham (2012) report that functional limitations associated with reading are best predicted by function of the central 5 degrees of the visual field. They assessed reading ability using a self-report, and assessed the visual field binocularly using a threshold paradigm.

1.5.4 Quality of life

Quality of life is an “individual’s perception of their position in life in relation to their goals, expectations, standards, and concerns” (World Health Organization, 2013), and quality of life instruments assess the impact of a disease or treatment on a patient’s life. Gutierrez et al., (1997) found a linear decline in health related quality of life with greater visual field loss in glaucoma patients, and suggests that self-reports of vision related quality of life measures are sensitive to visual field loss. These findings support those of other studies who also report a decline in quality of life with increased severity of visual field loss (Gutierrez et al., 1997; Parrish et al., 1997; Sherwood et al., 1998; Nelson-Quigg et al., 1999; Odberg et al., 2001; Janz et al., 2001; Altangerel et al., 2003; Nelson et al., 2003; Hyman et al., 2005; Ringsdorf et al., 2006). McKean-Cowdin et al., (2007) suggests that even early visual field loss can affect quality of life.

1.6 Ideal functional visual field assessment

Since visual field loss is associated with activity limitation and participation restriction, as outlined above, then to gain a full picture of a patient’s impairment in the low vision assessment a functional visual field assessment would be appropriate. What parameters should such an assessment have?

The ideal functional visual field test would assess binocular function, since binocular visual field assessment represents functional abilities better than monocular assessment, especially in individuals with visual impairment (Nelson-Quigg et al., . 2000; Schneck et al., 2010; Asaoka et al., 2011; Crabb et al., 2013). This differs from the usual monocular field assessments used for diagnosing and monitoring progression of disease.

It might be preferable for the ideal functional field test to also assess the visual field beyond the central 30 degrees commonly assessed diagnostically. The peripheral visual field has been shown to contribute to postural stability (Elliott et al., 1995; Berencsi et al., 2005; Kotecha et al., 2012; 2013). It has also recently been demonstrated that patients with similar central visual field loss may have very different visual fields in the periphery (Moenter et al., 2017) suggesting that the assessment of the peripheral visual field may be necessary to accurately reflect patients' real life perception of their visual field, and to determine the functional consequences of field loss.

It is important that a functional fields test is able to differentiate between individuals with different levels of perceived or measured visual difficulty. At its simplest, a functional field test would be able to reliably discriminate between people who did and did not have difficulty with an activity. Beyond this, a discriminatory test might be able to accurately categorise people with different levels of loss.

Long test durations can adversely affect patient concentration and compromise the reliability of visual field results (Gardiner & Demirel, 2008; Henson & Emuh, 2010). An ideal functional visual field assessment should be of an acceptable test duration and difficulty for patients.

It is also important that the output of the visual field test will be in a format that can be easily understood by patients and non-optical professionals including rehabilitation officers undertaking mobility training. Friedman et al., (1999) report that there exists a disparity between the views of clinicians and patients about their condition, and suggest that explaining the visual field results in a clear and concise manner may influence how well they respond to important aspects of their follow-up care.

In practical terms, it would also be important for the visual field assessment to utilise existing or easily available equipment if it were to be incorporated into clinical practice.

1.7 Current methods of functional visual field assessment

While the effects of visual field loss on the ability to perform activities of daily living and overall quality of life is well documented, the visual field test is seldom performed as part of low vision assessment. If available to the low vision practitioner, previous, usually monocular visual field plots are used to attempt to relate field loss to difficulties the patient may encounter. There remains no standard reference method for assessing the visual field binocularly, and determining the functional consequences of visual field loss.

There are several reasons why functional visual fields may not be routinely assessed. Currently available conventional visual field assessments are designed to detect and monitor the progression of disease and may not be considered relevant to low vision assessment. The visual field is also not as easy to reduce to quantitative terms as is visual acuity (Esterman, 1967). While the peripheral visual field past 30 degrees may more accurately reflect the impact of visual field loss on function, in particular with mobility (Eliott et al., 1995; Berensci et al., 2005; Kotecha et al., 2012; 2013), currently available diagnostic assessments of the visual field are often confined to the central 25-30 degrees of the visual field. Diagnostic tests are also monocular, and often utilise a threshold paradigm; both rendering the assessment long and demanding for patients with reduced vision. Even the Esterman assessment, the only functional binocular visual field assessment available and one that utilises a suprathreshold paradigm, can take up to ten minutes to complete in normally sighted individuals and will take longer in patients with reduced vision. It is likely that low vision practitioners see no merit in conducting lengthy, difficult, and often disheartening assessments of the visual field that are not optimised for reflecting the functional consequences of visual field loss in individuals with low vision.

Previous studies have assessed binocular visual fields in different ways to reflect functional difficulties with activities of daily living and these are now reviewed below (summarised in Table 1.2). The degree of association between the visual field variable and functional ability is provided using results of bivariate analyses. The size of the linear correlation coefficient following bivariate analysis is represented by an R^2 value in Table 1.2. A value of 0 indicates that the model explains none of the variability of the response data, whereas a value of 1 indicates that the model explains all the variability of the response data.

The R^2 values in Table 1.2 range between 0.01 and 0.70. Whilst some values might be considered relatively low, values are generally in keeping with those of other studies comparing visual function with self-reported difficulty (Gutierrez et al., 1997; Parish et al., 2007; Tabrett & Latham, 2011). It is known that self-reported difficulty is influenced by other factors than visual function, including psychosocial characteristics such as depression (Tabrett & Latham, 2011), and as such only a proportion of variance would be expected to be explained by visual variables.

Study	Subjects	Visual field assessment	Visual field quantification	Outcome measure	Correlation coefficients and significance
Integrated visual fields					
Black et al., 2011	74 glaucoma	Monocular HFA 24-2	IVF, best location (Nelson-Quigg et al., 2000)	6 min walk test (Lord & Menz, 2002)	R^2=0.03 p>0.05
				Timed up and go test (Podsiadlo & Richardson, 1991)	R^2=0.06 p>0.05
				Physical Activity Scale for the Elderly (PASE) (Washburn et al., 1993)	R^2=0.29 p<0.05
Burton et al., 2015	54 glaucoma 38 normals	Monocular HFA 24-2	IVF, best location (Nelson-Quigg et al., 2000)	Reading speed	R^2 not provided p=0.38
Crabb & Viswanathan, 2004	48 glaucoma	Monocular HFA 24-2	IVF, best location (Nelson-Quigg et al., 2000)	10 item questionnaire (Lester & Zingirian, 2002)	NA
		Binocular Esterman	Esterman efficiency score		
Sumi et al., 2003	147 glaucoma	Monocular HFA 30-2	IVF, best location averaged over the subfield or test point cluster	30 item questionnaire (Sumi et al., 1995)	R^2=0.40 p<0.005
			Better eye mean deviation		R^2=0.41 p=0.005
			Worse eye mean deviation		R^2=0.35 p<0.005
Turano et al., 2004	1504 older adults	Monocular 81-point 24dB suprathreshold (on HFA)	IVF, best location (Nelson-Quigg et al., 2000)	Mobility course percentage preferred walking speed and number of errors	R^2 not provided

Esterman					
Choy et al., 1986	47 glaucoma	Binocular Esterman	Binocular Esterman efficiency score	5 item visual disability questionnaire	R^2=0.42 p=0.0002
		Monocular Esterman Monocular manual Goldmann kinetic perimetry	Monocular Esterman efficiency score		R^2=0.45 p=0.0001
			Binocular visual field extent including scotomas		R^2=0.40 p=0.0003
			Binocular visual field extent ignoring scotomas		R^2=0.42 p=0.0003
Fujita et al., 2008	144 glaucoma	Binocular Esterman	Esterman efficiency score	10 item ADL questionnaire	R^2=0.48 p<0.0001
Jampel et al., 2002b	237 glaucoma	Binocular Esterman	Esterman efficiency score	25 item National Eye Institute Visual Function Questionnaire (NEI VFQ-25) (Mangione et al., 1998b)	R^2=0.32 p=0.001
		Monocular HFA 24-2	Better eye mean deviation		R^2=0.32 p=0.001
			Worse eye mean deviation		R^2=0.21 p=0.003
Lee et al., 2013	60 glaucoma	Binocular Esterman	Esterman efficiency score	25 item National Eye Institute Visual Function Questionnaire (NEI VFQ-25) (Mangione et al., 1998b)	R^2=0.16 p<0.05
Mills & Drance 1986	42 glaucoma	Binocular Esterman	Esterman efficiency score	15 item questionnaire	R^2=0.10-0.35 p not provided
Nelson et al., 2003	47 glaucoma	Binocular Esterman	Esterman efficiency score	Glaucoma Visual Disability questionnaire (GQL-15) (Nelson et al., 2003)	R^2=0.15 p<0.001
		Monocular HFA 24-2	Mean deviation		R^2=0.36 p<0.0001
Noe et al., 2003	79 glaucoma	Binocular Esterman	Esterman efficiency score	The Impact of Vision Impairment Questionnaire (Weih et al., 2002)	R^2=0.03 p=0.15

Parrish et al., 1997	147 glaucoma	Binocular Esterman	Esterman efficiency score	The Visual Function Index (VF-14) (Steinberg et al., 1994)	R^2=0.34 p<0.001
Turano et al., 1999	10 glaucoma 9 normals	Binocular Esterman	Esterman efficiency score	Time to complete mobility courses	R^2=0.15-0.18 p<0.01
		Monocular HFA 24-2	Mean deviation		R^2=0.24-0.32 p<0.01
Viswanathan et al., 1999	123 glaucoma	Binocular Esterman	Esterman efficiency score	10 item questionnaire (Mills & Drance, 1986)	R^2=0.17-0.30 p=0.001-0.009
Yanagisawa et al., 2012	50 mixed low vision	Binocular Esterman	Esterman efficiency score	25 item National Eye Institute Visual Function Questionnaire (NEI VFQ-25) (Mangione et al., 1998b)	R^2=0.12 p=0.02
		Monocular manual Goldmann kinetic III-4e	AMA score (Rondinelli et al., 2009)		R^2=0.04 p=0.15
			Functional field score (Colenbrader et al., 1993)		R^2=0.08 p=0.05
			Solid angle		R^2=0.07 p=0.07
			Estimated binocular field extent		R^2=0.05 p=0.13
Binocular threshold					
Black et al., 1997	10 RP 9 normals	Binocular HFA 30-2	Average visual field extent along 8 principal meridians	Mobility course percentage preferred walking speed and number of errors	R^2=0.23-0.70 p not provided
Tabrett & Latham 2012	100 mixed low vision	Binocular HFA 30-2	Mean threshold	Modified Activity Inventory	R^2=0.12-0.37 p<0.001
Binocular suprathreshold					
Jampel et al., 2002a	101 glaucoma	Custom central 24dB suprathreshold test	Percentage of points seen	25 item National Eye Institute Visual Function Questionnaire	R^2=0.16 p<0.001

		Custom central 26dB suprathreshold test		(NEI VFQ-25) (Mangione et al., 1998b)	$R^2=0.19$ $p<0.001$
		Custom peripheral 20dB suprathreshold test			$R^2=0.21$ $p<0.001$
		Custom peripheral 22dB suprathreshold test			$R^2=0.16$ $p<0.001$
		Binocular Esterman	Esterman efficiency score		$R^2=0.19$ $p<0.001$
		Monocular HFA 24-2	IVF, best location (Nelson- Quigg et al., 2000)		$R^2=0.23$ $p>0.001$
			IVF, binocular summation (Nelson-Quigg et al., 2000)		$R^2=0.18$ $p<0.001$
Binocular kinetic					
Bibby et al., 2007	30 mixed low vision	Binocular kinetic IV-4e (on HFA)	Percentage of a sphere (Lovie-Kitchin et al., 1990)	Independent Mobility Questionnaire (Turano et al., 1999)	$R^2=0.57$ $p<0.05$
Lovie-Kitchin et al., 2010	109 mixed low vision 41 normals	Binocular kinetic IV-4e (on HFA)	Solid angle (Arditi, 1988; Weleber & Tobler, 1986)	Mobility course percentage preferred walking speed	$R^2=0.42$ $p<0.001$
				Number of errors	$R^2=0.45$ $p<0.001$
Haymes et al., 1996	18 RP	Binocular manual Goldmann kinetic III-4e	RP concentric field rating (Haymes et al., 1996)	Mobility course percentage preferred walking speed: Residential street	$R^2=0.01$ $p>0.05$
				Small business area	$R^2=0.41$ $p<0.05$

				Indoor shopping mall	R^2=0.59 p<0.05
Haymes et al., 2002	120 mixed low vision	Binocular manual Goldmann kinetic III-4e	Anatomical total visual field score (Haymes et al., 1996)	MLVAI desk based clinical assessment of ADL performance (Haymes et al., 2001)	R^2=0.31 p<0.001
Lovie-Kitchin et al., 1990	9 mixed low vision 9 normals	Binocular kinetic (Hablin Lister arc perimeter)	Solid angle (Arditi, 1988; Weleber & Tobler, 1986)	Time taken to complete mobility course	R^2=0.30 p<0.02
				Number of errors	R^2=0.58 p<0.001

Table 1.2 Summary of studies that assess the visual field binocularly and relate field data with functional ability. R^2 values are provided where relevant.

1.7.1 Integrated visual fields (IVF)

It has been suggested that it is possible to predict binocular visual field sensitivity from monocular visual field test results with good accuracy in patients with glaucomatous visual field loss, and that binocular threshold testing may have little to add over a statistical combination of the two monocular threshold tests (Nelson-Quigg et al., 2000). Numerous studies have combined monocular visual field results to construct a binocular visual field or integrated visual field (IVF) in patients with glaucoma (Crabb et al., 1998; Nelson-Quigg et al., 2000; Jampel et al., 2002a; Sumi et al., 2003; Crabb & Viswanathan, 2004; Aspinall et al., 2008; Asaoka et al., 2011; Black et al., 2011; Lisboa et al., 2013; Crabb et al., 2013; Burton et al., 2015), samples of older adults (Turano et al., 2004; West et al., 2005; Freeman et al., 2007) and patients with central visual loss (Timmis & Pardhan, 2012). The majority of these studies assess the central 24 degrees of the visual field using the monocular, threshold, 24-2 assessment on the HFA (Crabb et al., 1998; Jampel et al., 2002a; Crabb & Viswanathan, 2004; Aspinall et al., 2008; Asaoka et al., 2011; Black et al., 2011; Timmis & Pardhan 2012; Crabb et al., 2013; Lisboa et al., 2013; Burton et al., 2015), although some studies use the threshold 30-2 programme (Nelson-Quigg et al., 2000; Sumi et al., 2003), and others combine monocular suprathreshold results (Freeman et al., 2007; West et al., 2005; Turano et al., 2004). Integrated visual fields provide a rapid estimate of a patient's binocular field without extra perimetric examination (Crabb et al., 1998; Nelson-Quigg et al., 2000; Asaoka et al., 2011), although the construction of integrated visual fields assumes the availability of previously assessed monocular field plots. Since results from conventional diagnostic plots are used to construct an IVF, the method also assumes that the central 25-30 degrees of the visual field is of primary interest.

Although binocular threshold visual fields can be estimated by integrating monocular results, any relationship with reported functional ability appears dependent on the degree of summation used (Jampel et al., 2002a; Sumi et al., 2003). Binocular visual field assessment includes the effect of binocular summation (Esterman, 1982; Ayala, 2012). Binocular summation is the visual process by which input from the two eyes are combined to form the binocular percept (Wood et al., 1992). A binocular visual field assessment does not ignore intact field areas in one eye that may compensate for areas of field loss in the other (Rondinelli et al., 2009). Therefore, in cases of asymmetric field loss in particular, binocular visual field assessment is substantially better than the field of vision of either eye alone (Rondinelli et al., 2009).

Nelson Quigg et al., (2000) compared methods of predicting binocular visual field sensitivity from monocular visual field data in a sample of patients with glaucoma. Four binocular sensitivity prediction models were evaluated. The "best eye" model involved mean deviation predictions based on individual values for the most sensitive eye. The "average eye" model involved predictions based on the average sensitivity between eyes at each visual field location. In the "best location" model predictions were based on the highest sensitivity between eyes at each visual field location. The final model "binocular summation" involves predictions based on binocular summation of sensitivity between eyes at each location. Mean deviation scores derived from these models were compared to actual binocular sensitivities assessed using a binocular threshold 30-2 test on the HFA. It was found that the "binocular summation" and "best location" models provided better predictions of binocular visual field sensitivity than the other two models. The majority of studies that combined monocular threshold field results to construct a binocular visual field utilise the "best location" model (Crabb et al., 1998; Jampel et al., 2002a; Sumi et al., 2003; Crabb & Viswanathan, 2004; Aspinall et al., 2008; Asaoka et al., 2011; Black et al., 2011; Timmis & Pardhan 2012; Crabb et al., 2013; Lisboa et al., 2013; Burton et al., 2015).

Crabb & Viswanathan (2004) constructed “best location” IVF and determined perceived function of nine mobility tasks including “do you trip on things or have difficulty with stairs?” and “do you bump into things sometimes?”. Receiver operator characteristic (ROC) analysis was used to compare the diagnostic precision of Esterman visual fields and IVF at selecting patients with a perceived difficulty with a visual task. Responses to the nine-item questionnaire could be predicted by both the IVF and the Esterman. It was suggested that the IVF is a better indicator of mobility difficulty in individuals with glaucomatous field loss than the Esterman assessment.

Black et al., (2011) also related IVF to visual function. Physical performance and self-reported activity level were combined to produce an overall functional status score. Greater visual impairment was associated with poorer functional status (R^2=0.29, $p<0.05$). A similar relationship was found when Aspinall et al., (2008) compared the IVF with perceived mobility function (R^2=0.26). Jampel et al., (2002a) compared the IVF to Esterman, and custom suprathreshold assessments with stimulus intensities between 10dB and 26dB and found that a global score derived from a combination of two monocular fields correlated better with patient assessment of vision than did the Esterman and four novel binocular visual field tests (Figure 1.6).

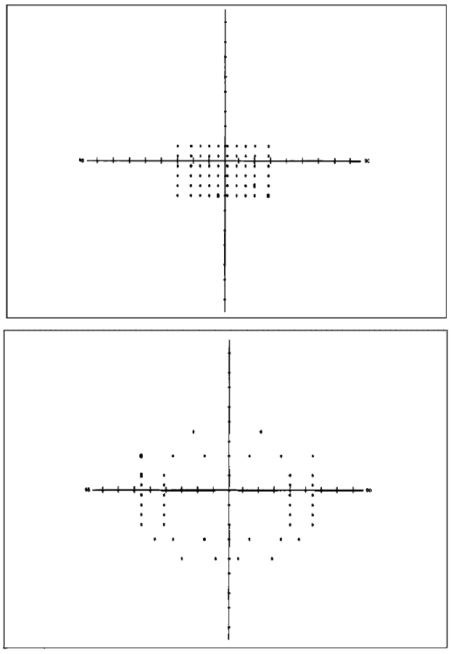


Figure 1.6 Central and peripheral custom visual field test patterns created by Jampel et al., (2002a)**.**

Integrated visual fields provide a rapid estimate of the binocular field without the need for extra examination (Crabb et al., 1998; Nelson-Quigg et al., 2000; Asaoka et al., 2011), and studies suggest IVF scores relate to general visual function, and mobility function. However this method uses results from conventional diagnostic plots to construct the binocular field, assuming the availability of previously assessment plots, and that the central 25-30 degrees of the visual field is of primary interest.

1.7.2 Esterman

The Esterman test is a binocular, 10dB suprathreshold visual field assessment with 120 points extending approximately 35 degrees superiorly, 55 degrees inferiorly, and 80 degrees laterally from fixation (Figure 1.7). The only currently available binocular functional field assessment, the Esterman is used to determine the extent of visual fields in UK drivers (Driver and Vehicle Licensing Agency, 2016). The scoring of the Esterman test (percentage of points seen) involves giving greater weight to areas of the visual field deemed more important for human activities including working, eating, walking, and reading (Esterman 1967; 1968; 1982). Esterman (1967; 1968; 1982) suggests that the central part of the visual field is more valuable than the periphery, the lower hemisphere more useful than the upper, and the peripheral field near the horizontal meridian more important than any other meridian for human activities.

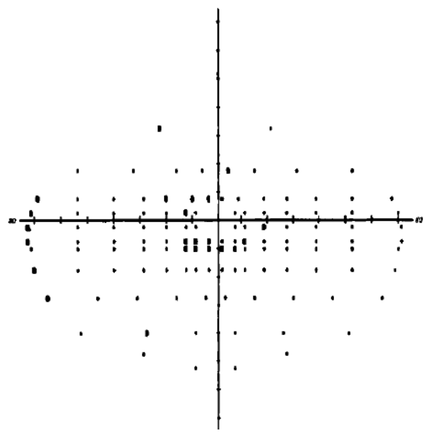


Figure 1.7 Binocular Esterman visual field test pattern (Esterman 1982, HFA).

The Esterman test has been found a useful tool for assessing visual disability in a group of glaucoma patients with severe field loss (Mills & Drance, 1986; Nelson et al., 2003). Nelson et al., (2003) found that binocular visual field loss (determined with Esterman) was strongly associated with dark adaptation, glare disability, activities related to functional peripheral vision, and outdoor mobility tasks. Fujita et al., (2008) examined glaucoma patients with bilateral visual field loss and found that the Esterman score is a good indicator of difficulties of daily living. Viswanathan et al., (1999) also showed that the Esterman score correlates with a disability questionnaire. They found that questions that most strongly associated with Esterman scores related to bumping into things, problems with stairs, and finding things that have been dropped.

In contrast to these studies, Parrish et al., (1997) found that none of the domains on the Medical Outcome Study 26-item Short Form Health Survey demonstrated more than a weak correlation with Esterman scores. Similarly, Jampel et al., (2002b) found that correlation between Esterman and self-report (as assessed by the NEI VFQ) in a group of 237 glaucoma patients was weak. One study suggested that visual acuity is a stronger determinant that the Esterman score of restriction of participation of activities of daily living in individuals with glaucoma (Noe et al., 2003). These studies use more general quality of life instruments, whereas in studies discussed previously (Mills & Drance, 1986; Nelson et al., 2003) more specific visual disability instruments are administered.

Limitations of the Esterman test are well documented, and include the clustering of scores at the higher end of the scoring scale regardless of the severity of impairment (Harris & Jacobs, 1995; Parish et al., 1997; Mills 1998; Turano et al., 1999; Jampel et al., 2002a; 2002b; Noe et al., 2003; Nelson et al., 2003). As with all suprathreshold assessments, the Esterman produces only a pass / fail at each test point (Crabb et al., 1998; Crabb & Viswanathan, 2004), and it is not possible to judge whether a defect is absolute or relative (Ayala, 2012). Problems with the distribution of test points have also been reported, with one study suggesting that the point distribution does not reflect its claimed functional significance (Mills et al., 1993), and another suggesting that there are few test points in the functionally important central 10 degrees of the field (Rauscher et al., 2010). There is no direct monitoring of fixation with the Esterman test since it assesses the visual field binocularly (Esterman, 1982; Crabb et al., 1998; Crabb & Viswanathan, 2004; Ayala, 2012). However, although control of fixation is an important component of perimetric testing and reliability of response (Henson et al., 1996), and the lack of fixation control may inflate the number of points seen, it is suggested that a binocular assessment of the visual field mimics more accurately the 'real' field of view (Crabb et al., 1998).

Turano et al., (1999) found that despite the suprathreshold Esterman assessment being performed binocularly and testing points extending to 80 degrees from fixation, the threshold HFA 24-2 (performed monocularly and extending only to 24 deg) was better correlated with the walking speeds of 47 glaucoma subjects. They suggest that an improved correlation of mobility with functional testing may be obtained by combining the wide binocular testing area of the Esterman with a threshold testing strategy.

Proposing to devise a binocular visual field test that correlated better with patient reported assessment of vision than the Esterman, Jampel et al., (2002a) adopted previous ideas (Choy et al., 1986; Harris & Jacobs, 1995) and decreased the intensity of the stimulus used in the Esterman tests to expand the useful range of scores. They tested the central and peripheral visual field separately using four binocular suprathreshold custom tests (Figure 1.6) with stimulus intensities of between 10db and 26dB and found that the score derived from a combination of monocular threshold fields correlated better with patient assessment of vision than did the Esterman and the custom suprathreshold assessments. Like Turano et al., (1999), Jampel et al., (2002a) also suggest that a threshold binocular visual field test may yield stronger correlation with functional ability of individuals with glaucomatous field loss than a suprathreshold test.

The Esterman test assesses the visual field binocularly, and considers the visual field past 30 degrees eccentricity, although some studies suggest it is not a useful indicator of functional ability. Regardless of the degree of visual field loss, the assessment has been shown to cluster scores at the high end of scoring. It is also not known whether the asymmetric distribution of points is optimal to reflect functional difficulties in patients with field loss.

1.7.3 Binocular threshold visual field

Another method of determining the functional visual field is to use traditional monocular tests binocularly (Black et al., 1997; Nelson-Quigg et al., 2000; Tabrett & Latham, 2009; Tabrett & Latham, 2011). Unlike with integrated visual fields, here the absolute binocular thresholds are determined rather than artificially calculated values. Tabrett & Latham (2012) found that assessing visual field binocularly using a threshold test strategy can represent the functional abilities of people with visual impairment. Utilising an existing threshold assessment binocularly such as the HFA central 24-2 or 30-2 avoids ceiling effects in scoring scales (Bengtsson & Heijl, 1998). The HFA 24-2 and 30-2 have also demonstrated a stronger relationship with self-reported functional limitations compared with suprathreshold strategies (Nelson et al., 2003).

There are limitations of implementing a conventionally monocular threshold assessment, such as the HFA 30-2 or 24-2 binocularly. As with the Esterman test, a binocular threshold score has no value in diagnosis (Esterman, 1982). Binocular visual field assessment eliminates normal blind spots and therefore invalidates the conventional fixation indices that utilise the blind spot (Esterman, 1982, Tabrett & Latham, 2012). Furthermore, there is a limited ability to compare absolute thresholds from binocular assessment to normative data as normal binocular values are currently unknown (Tabrett & Latham, 2012). There is no standard normative data or analysis procedures available to test the binocular visual field with clinical or custom devices in a non-conventional manner. The amount of convergence exerted under binocular conditions in a bowl perimeter cannot be monitored (Rondinelli et al., 2009), and so maintaining binocular fusion for a prolonged period may be problematic for patients, in particular those who exhibit large inter-ocular differences in visual acuity. It has also been suggested that the large inter-ocular differences in visual acuity that low vision patients can exhibit, may behave as a dissociative factor to binocularity (Rundstrom & Eperjesi, 1995). However, no such difficulties have been reported in the numerous studies that have utilised conventionally monocular tests binocularly (Black et al., 1997; Nelson-Quigg et al., 2000; Leat & Lovie-Kitchin, 2006), or used the Esterman binocular fields test (Mills and Drance, 1986; Choy et al., 1986; Harris & Jacobs, 1995; Parrish et al., 1997; Viswanathan et al., 1999; Turano et al., 1999; Jampel et al., 2002a; 2002b; Nelson et al., 2003; Noe et al., 2003; Crabb & Viswanathan, 2004; Chisholm et al., 2008; Kotecha et al., 2008; Fujita et al., 2008; Yanagisawa et al., 2011; Ayala, 2012).

A binocular threshold assessment provides a comprehensive examination of the visual field, with the option of utilizing currently available tests, and studies have demonstrated that results from a binocular threshold assessment relate well to perceived function. However it is known that threshold test strategies are more time consuming, and potentially more difficult for a patient with reduced vision to perform. It has also been suggested that threshold sensitivities determined in defective areas of the visual field are not repeatable (Gardiner et al., 2014).

1.7.4 Kinetic

Several studies have used a binocular kinetic field assessment to compare to functional ability (Lovie-Kitchin et al., 1990; Haymes et al., 1996; 2002; Bibby et al., 2007; Hassan et al., 2007; Azoulay et al., 2015). Haymes et al., (1996) used the Goldmann perimeter and a III-4e (10dB) target to assess the binocular field of RP subjects and compared field results to mobility performance. A scoring method devised to represent the residual visual field involved rating the amount of extension of peripheral visual field loss into the central visual field (RP Concentric Field Rating), and was related to indoor mobility function. Binocular kinetic Goldmann assessments have also been found to relate to self-reported mobility in mixed low vision samples (Bibby et al., 2007). Lovie-Kitchin et al., (1990) assessed the binocular visual field kinetically using a Hablin Lister arc perimeter in a small sample of subjects, of which half had mixed visual impairment, and scored the residual field as a solid angle in steradians. Mobility performance was assessed on an indoor course. The total visual field score related significantly to the time taken to complete the course, and the number of errors made. In another study, Lovie-Kitchin et al., (2010) assessed the binocular visual field of a mixed low vision sample using a kinetic paradigm, and their performance of a mobility course. They found that the visual field correlated with walking speed and the number of obstacle errors. Haymes et al., (2002) also measured the binocular visual field of 120 low vision patients kinetically and found that of all clinical measures, visual fields had the weakest correlation with overall ADL performance. They suggest that this is because, with exception of mobility, relatively few activities of daily living involve peripheral vision.

By continuing to move a kinetic stimulus towards the centre of the visual field after it has been detected, the presence of internal scotomas in mapped isopters can be examined. Choy et al., (1986) assessed the visual field using a III-4e stimulus target on a Goldmann perimeter manually, examining internal scotomas, and related scores to self-reported function. They also derived a visual field score that ignored the presence of internal scotomas. Perceived function related similarly to the field extent including scotomas and excluding scotomas, suggesting that no further information is provided by undertaking a more comprehensive, and time consuming kinetic assessment that assessed internal scotomas.

1.7.5 Automated combined kinetic and static perimetry

While no study has related visual field data from a custom, combined kinetic-static assessment to functional ability, the Octopus 101 perimeter has been used to create such a visual field assessment (Pineles et al., 2006). The use of the Octopus perimeter was proposed to create an automated test that combines the advantages of static and kinetic perimetry and produces equivalent results, while not requiring examiner expertise. In another study, Moenter et al., (2017) investigated the relationship between central and peripheral glaucomatous visual field, by assessing the central field using static automated perimetry and peripheral field with automated kinetic perimetry. In both these studies however, the combined assessments took greater than 10 minutes, which while suitable in research setting, is not appropriate in a clinical setting.

1.8 Visual field paradigms

It has been established that binocular visual field assessment can represent functional abilities whether kinetic, suprathreshold test strategies such as the Esterman visual field test, or threshold tests are used (Table 1.2). It is not known which visual field paradigm is preferable in producing an outcome that can be used clinically and best describes functional difficulty.

The closest visual field tests to a 'gold standard' for assessing functional loss are the Esterman test (Esterman, 1982) and IVF (Crabb & Viswanathan, 2004). The Esterman assessment adopts a suprathreshold paradigm, which Henson & Artes (2002) suggest is easier than threshold assessments, since there may be less uncertainty about whether a stimulus is seen or not. However, some studies suggest the Esterman is ineffective at reflecting functional ability of patients, so suggestions to improve the Esterman have been made. Jampel et al., (2002a) and Turano et al., (1999) suggested combining the wide binocular testing area of the Esterman with a threshold testing strategy. However, Henson & Emuh (2010) found that patients began exhibiting large waves of fatigue after approximately four minutes of visual field testing and a threshold assessment to 80 degrees eccentricity would likely extend the duration of the assessment significantly beyond this. It has also been suggested that the 10dB stimulus intensity adopted by the Esterman test is too bright (Harris & Jacobs, 1995; Parish et al., 1997; Mills, 1998; Turano et al., 1999; Jampel et al., 2002a; 2002b; Noe et al., 2003; Nelson et al., 2003) and that reducing the stimulus intensity may expand the useful range of scores (Choy et al., 1986; Harris & Jacobs, 1995). However, this has been examined and was not found to improve the assessment (Jampel et al., 2002a).

The IVF involves the assessment of the central visual field out to 25-30 degrees from fixation, monocularly, using a threshold paradigm. It has been established that monocular assessment of the visual field does not yield the closest approximation of a patient's real field of view, and a binocular assessment is more relevant to functional ability than monocular testing (Crabb et al., 1998). The potential importance of the peripheral visual field to determine the functional consequences of field loss (Moenter et al., 2017) may also need to be considered. Suprathreshold paradigms may also have advantages of speed and patient preference when compared with threshold perimetry (Henson & Artes, 2002).

The kinetic paradigm may be appropriate to consider for functional field assessment since it allows for the assessment of peripheral visual field quickly. Furthermore, the Riddoch phenomenon means that detection of a moving stimulus is easier than for a static stimulus (Hudson & Wild, 1994; Zeki & Ffytch, 1998), and this may be more evident in defective regions of the visual field (Safran & Glaser, 1980). Kinetic perimetry, while useful for assessment of the peripheral field, has limitations. Single responses to a kinetic stimulus close to threshold are variable (Lynn et al., 1991), and Moenter et al., (2017) suggest repeated presentations may be necessary to reduce the impact of outliers. However, repeated presentations extend the test duration. Further vectors need to be assessed to determine the presence of internal scotomas. These factors make kinetic perimetry difficult to automate, and a manual assessment is often lengthy, requires a trained practitioner to perform, and yields results that are highly dependent on the competence of the practitioner.

The most appropriate paradigm(s) for a functional visual field test to use are therefore as yet unclear.

1.9 Relevant areas of the functional visual field

1.9.1 Central and peripheral field

The term "central visual field" is used throughout this thesis to refer to the visual field within the central 25-30 degrees radius from fixation, that is assessed in conventional diagnostic tests, and the term "peripheral visual field" is used to refer to the visual field beyond this point (Esterman, 1982; Moenter et al., 2017). There are some studies that propose the central visual field is more strongly related to mobility function than the peripheral field. Hassan et al., (2007) assessed navigation performance in 20 normally sighted subjects, with their field of view constricted to 10, 20 and 40 degrees in diameter, and suggested that the field of view required for navigation is between 10.9 and 32.1 degrees depending on contrast conditions. Lovie-Kitchin et al., (1990) also assessed mobility performance on an indoor course, and assessed the binocular visual field out to 90 degrees on a Hablin Lister arc perimeter. They proposed the central 37 degrees is most important for mobility function in individuals with low vision. Tabrett & Latham (2012) who assessed the central 30 degrees of the visual field, found that in a sample of low vision participants the central 10-30 degrees of the visual field best predicted visual related activity limitation in mobility tasks. Similarly, Sumi et al., (2003) used the 30-2 test in glaucoma patients and reported that perceived function in mobility tasks was best explain by the function of the inferior 5 degrees from fixation.

However, it has been suggested that refractive correction for central visual impairment alone may be insufficient to effectively decrease the rates of falls owing to visual impairment (Patino et al., 2010). It has also been reported that a loss in the peripheral visual field is a greater determinant of mobility function. Freeman et al., (2007) found that in a population sample of older adults the peripheral 20 to 60 degrees remained statistically significantly correlated with the risk of falling after they attempted to determine the independent associations of the central and peripheral visual field deficits, whereas the central visual field (0 -20 deg) lost its statistical significance. Geruschat et al., (1998) measured the monocular visual field of RP subjects by kinetic perimetry, and defined visual field extent as a dichotomous variable that indicated whether the visual fields were contained within the central 20 degrees, or whether they extended beyond the central 20 degrees. They found the visual field extent significant correlated with mobility function, as assessed on a mobility course, with worse function in subjects with fields contained within the central 20 degrees. Furthermore, Genensky (1976) suggest that a central scotoma less than or equal to 25 degrees is unlikely to impede mobility function significantly, while a peripheral visual field defect limiting two quadrants to 45 degrees or less is likely to cause problems with mobility function.

Turano et al., (2005) and Freeman et al., (2007) however indicate the importance of both the central and peripheral visual field for mobility. They suggest that that the central field is used to guide walking, and the peripheral field to establish and update an accurate representation of spatial structure for navigation (Turano et al., 2005). Furthermore, it is reported that both central and peripheral visual field deficits can produce incorrect sensory inputs through misjudgements of distances and/or misinterpretations of spatial information, such as the correct nature of a group surface, moving stimuli or a shadow (Lord et al., 2007).

1.9.2 Superior and inferior field

Numerous studies have suggested the particular significance of the inferior visual field for mobility function (Lovie-Kitchin et al., 1990; Turano et al., 2004; Coleman et al., 2007; Black et al., 2008; Marigold & Patla, 2008; Black et al., 2011). Visual field loss in the inferior mid-periphery (20 – 40 degrees) was found to adversely affect mobility more than loss of the visual field in other areas in one study (Lovie-Kitchin et al., 1990). Turano et al., (2004) report that visual field loss in the central and lower peripheral regions is associated with comparable decrements in walking speed. Similarly, Black et al., (2011) suggest that inferior visual field loss is the strongest predictor of self-reported mobility function and mobility performance. Black et al., (2004) used a swaymeter to measure postural sway, and found that greater inferior visual field loss was associated with increased postural sway suggesting that the inferior visual field may provide a stronger contribution to postural stability than the superior visual field. Coleman et al., (2007) merged monocular 30 degree suprathreshold visual field results, and recorded fall frequency retrospectively. They found that the odds of falling among older women with severe inferior visual field loss, when compared with no inferior loss, was 91% higher, whereas the odds of falling among those with severe superior visual field loss, when compared with no superior visual field loss, was 74% higher. Marigold & Patla (2008) used a small sample of normally sighted individuals to perform walking trials with and without glasses that simulated inferior visual field loss. They found that with the inferior visual field blocked, participants reduced speed and step length, suggesting that information from the lower visual field is normally used when walking across multi-surface terrain.

Freeman et al., (2007) and Tabrett & Latham (2012) however report a similar degree of association between inferior and superior visual field areas and function. The difference in the significance of the inferior visual field for mobility function suggested in studies is likely a result of the varying degrees of visual field loss in their sample groups, and the differences in the outcome measures used. Lovie-Kitchin et al., (1990) used a small sample (n=18) of which half had mixed visual impairments, and the remaining half had no visual impairment. Black et al., (2008; 2011) used a sample of glaucoma participants. Turano et al., (2004) and Coleman et al., (2007) used samples of normally sighted older adults, and Marigold & Patla (2008) used a small sample (n=20) of normally sighted individuals and simulated field loss. Therefore the inferior field bias is particularly of note in samples with early, simulated, or no visual field loss. There is no known evidence of inferior visual field bias with more extensive field loss.

The limitation of the majority of the above studies is that it is unlikely individuals will present with isolated inferior field loss. Those with inferior field loss are likely to have worse overall visual fields, and so the inferior visual field becomes an indicator of worse overall field loss (and therefore function). Marigold & Patla (2008) avoided this by using a sample of normally sighted individuals with simulated field loss, and Coleman et al., (2007) by comparing subjects with inferior visual field loss to those without inferior field loss, and not comparing inferior loss to superior loss.

1.10 Quantification of visual field loss

Studies utilising monocular threshold assessments of the visual field often use readily available visual field indices, such as mean deviation and pattern standard deviation. However, since normative or reference values are not available for binocular threshold data, other methods of quantifying the visual field must be considered.

While Leat & Lovie-Kitchin (2006) used binocular mean deviation scores as an outcome measure in one study, other studies that have assessed the visual field binocularly using a threshold paradigm have utilised other methods of quantifying the visual field. Tabrett &

Latham (2012) calculated the mean threshold of test points and used this as their main outcome measure, avoiding the need for reference values.

In another study, Black et al., (1997) manually derived visual field extent from binocular threshold field results. Statokinetic dissociation is a limitation of this method. Statokinetic dissociation, a term first referenced by Riddoch et al., (1917), describes the difference in visual field sensitivity when the field is assessed using static and kinetic paradigms. Due to this phenomenon, there will likely be a difference between measured visual field extent, and derived field extent.

The binocular visual field assessed using a suprathreshold paradigm can be quantified in the same way as a monocular assessment, using total percentage of points, or in the case of the Esterman assessment the Esterman Efficacy Score.

The kinetic visual field has been quantified in previous studies in several ways. Many studies have calculated the solid angle (degrees^2) subtended by an isopter (Weleber & Tobler, 1986; Arditi, 1988; Lovie-Kitchin et al., 1990; Lovie-Kitchin et al., 2010), and increasingly software such as Eye Suite (Haag Streit) is able to determine the solid angle of an isopter automatically (Peters et al., 2013). Alternatively, Moenter et al., (2017) used the mean isopter radius of 16 meridians as an outcome measure, allowing for the averaging of 3 repetitions per vector and the reproducibility of participants' individual responses to be analysed. Choy et al., (1986) also quantified the visual field using averaging of vectors.

Several other methods of quantifying the binocular kinetic visual field have been proposed (Marron & Bailey, 1982; Brown et al., 1986; Long et al., 1990; Beggs, 1991; Colenbrander et al., 1993; Haymes et al., 1996; 2002). The Anatomical Total Visual Field score was devised to score the functional visual field based on retinal anatomy and the representation of the visual field in the primary visual cortex (Haymes et al., 2002). They report an association between the visual field quantified in this way, and performance on a desk based clinical assessment. In another study, Haymes et al., (1996) propose a method of the scoring residual visual field in patients with RP; The RP Concentric Field Rating. This method involves rating the degree to which a large loss of the peripheral visual field extends into the central visual field. While simple and easily administered, the rating scale assumes symmetrical loss of the peripheral visual field, which is not always the case, even in patients with RP.

The American Medical Association (AMA) publishes guidelines for the evaluation of quantifying permanent visual impairment (Rondinelli et al., 2009). A component of the global summary measure of visual impairment (the Functional Vision Score) is the Functional Field Score (FFS). The FFS is determined by counting the number of points seen within a visual field isopter, using a predefined grid. This grid is monocular, and places more importance on the presumed functionally more important areas of the visual field: the central and inferior field areas (Colenbrander, 1994). This method or a variation of the FFS has been used in numerous studies (Choy et al., 1986; Haymes et al., 1996; 2002; Langelaan et al., 2005). However, the FFS method requires the visual field to be assessed kinetically and monocularly. This avoids the limitations of binocular assessment including fixation monitoring, and the required convergence in a bowl perimeter, but artificially constructs the binocular visual field by superimposing monocular field plots.

Haymes et al., (1996) scored the residual visual field using several methods and related field scores to mobility performance. While the residual visual field by all scoring methods (including the FFS and the percentage of visual field intact) correlated with mobility performance, the RP Concentric Field Rating method demonstrated the greatest correlations. In another study, Yanagisawa et al., (2011) investigated the relationship between methods used to evaluate the visual field, including the FFS, visual field area and visual field extent, and functional ability in patients with visual impairment. Conversely, they report weak correlations between methods of visual field examination and perceived visual function, and suggest that it is necessary to re-examine standard visual field evaluation methods.

1.11 Patients' opinions

Visual field assessments are demanding procedures for patients (Gardiner & Demirel, 2008), that patients dislike performing (Gardiner & Demirel, 2008; Glen et al., 2014). One qualitative study found that patients feel visual field tests are time consuming, old fashioned and tiring (Glen et al., 2014). Gardiner & Demirel (2008) showed that glaucoma patients rate the visual field assessment least favourably of all vision assessments. Reduced motivation can adversely affect patient concentration and compromise the reliability of visual field results (Gardiner & Demirel, 2008). It is important that the patient experience, when undergoing clinical tests is considered, although patients' opinion of vision testing is largely unreported. It has been suggested that this is due to difficulty objectively quantifying subjective, or "human factors" of field assessment (Gardiner & Demirel, 2008; Artes et al., 2016). However, acknowledging patients' experiences may help devise optimal strategies for functional vision assessment.

1.12 Clinical uses of a functional visual field test

The development of a binocular visual field test that can reflect functional difficulty would be a valuable tool in low vision assessment, including in the consideration of patients for visual impairment registration. Quantification of visual field loss, with an understanding of how scores relate to functional difficulty, would be helpful not only in assessing and managing the low vision patient, but also in determining robust criteria for visual impairment registration as compared to the unrepeatable systems currently in place in the UK.

Quantification of functional visual field loss could also help in determining minimum impairment criteria appropriate for entry to visually impaired sport (Ravensbergen et al., 2016). At present, criteria for entry into visually impaired sport are based on World Health Organization definitions of visual impairment and are the same for all sports, regardless of the impact of the visual impairment on sports performance. The International Paralympic Committee are moving towards the introduction of evidence-based sport-specific criteria for entry into visually impaired sport. For the successful introduction of such classification criteria, appropriate methods of assessing functional visual fields that reflect difficulty will be needed.

Most importantly for routine low vision assessment, patients are often not aware of their own field loss (Crabb et al., 2013). Making patients aware of their visual field would be helpful in assessing and managing the low vision patient, and also useful when liaising with other professionals, particularly those who may be providing mobility training to patients.

Chapter 2

Assessing functional ability

2.1 Introduction

While clinical measures of visual function such as the visual fields test provide a measure of visual impairment (World Health Organization, 2013), they provide little information about functional abilities of patients with visual impairment, and their level of visual disability. The nature and extent of vision disabilities depends on patients' functional limitations (Massof, 1998), which depend not only on a patient's impairment but also on their requirements and expectations. To determine the functional abilities of individuals with visual impairments, visual function assessment questionnaires or assessments of performance must be used.

2.2 Self-reported function

There are a large number of patient reported outcome (PRO) instruments used in optometry and ophthalmology research to identify areas of reduced function, to monitor changes in function, and to determine the success of interventions such as surgery or rehabilitation (Khadka et al., 2013).

Visual function assessment instruments contain a set of questions to assess function in activities of daily living (ADL). These questions are known as items. The nature of items included in questionnaires is dependent on the function of the instrument. The Activity Inventory (Massof et al., 1995; 1998; 2005a; 2005b; 2007) for example assesses perceived function in a wide range of everyday tasks, whereas the Independent Mobility Questionnaire (Turano et al., 1999; 2002) assesses mobility performance more specifically and therefore contains items that only relate to everyday mobility and orientation activities. Items in an instrument can be grouped with other related items into domains or subscales. Patients are asked to respond to each item in instruments with a dichotomous answer such as yes/no or agree/disagree, or a rating scale, which involves choosing a response out of a list of ordered response categories.

2.3 Scoring of perceived function

In the majority of visual function questionnaires, responses to items are ordered ratings of difficulty or level of agreement with a statement on a Likert scale (Massof, 2004). Assigning rank scores to these ratings and adding them together to produce an overall instrument score (summated scoring) is expected to relate to the degree of respondents' visual function (Massof, 2004), although this scoring method is not appropriate for these questionnaires (Massof & Rubin, 2001; Massof et al., 2007; Pesudovs et al., 2007; Khadka et al., 2013).

Summated scoring assumes responses to a questionnaire are interval based; i.e. each item represents equal difficulty and is therefore assigned an equal value (Pesudovs et al., 2007). For example, although reading small print in newspaper articles is more difficult than reading larger newspaper headlines (Massof & Rubin, 2001), the relative difficulty of the items is not considered when scores are simply summated. Assigning items equal value in scoring also increases noise in the measure (Norquist et al., 2004; Pesudovs et al., 2007), and damages the sensitivity of instruments to make meaningful comparisons between patients or clinical variables (Pesudovs et al., 2007; Khadka et al., 2013). Another limitation of summated scoring is the assumption of uniform changes between response categories, where a difficulty of 4 on a Likert scale is assumed to represent twice the difficulty of an assigned score of 2 on the same scale. However, the value of each category label is actually unknown, and so any sum of the ordinal numbers, or comparisons between categories is meaningless (Massof & Rubin, 2001).

A further limitation of assuming interval measurements is that resultant scores are test dependent; i.e. the overall summated score is dependent on the number of items responded to. Since an instrument's summated score is a function of the number of items responded to, missing data from items that are not addressed also cause problems with scoring. If items in an instrument are changed, comparisons with previous scores obtained from the pre-existing instrument will be invalidated (Reise & Heson, 2003).

Another implication of summated scoring is that a finite number of response categories imposes floor and ceiling effects on the overall score, and so the scale is compressed at its extremes leading to increased difficulty in discriminating between respondents (Stelmack & Massof, 2007).

2.3.1 Rasch analysis

Utilising ordinal data derived from these Likert rating scales does not make an allowance for the varying difficulties of different items, and therefore converting ordinal responses to interval data in Rasch analysis is indicated (Pesudovs et al., 2007). This removes noise from measurement which in turn improves sensitivity to change in function (Norquist et al., 2004) and correlations with other variables (Norquist et al., 2004; Khadka et al., 2013), allows the use of parametric statistics on the data (Khada et al., 2013), and provides more accurate measurements of perceived function (Stelmack & Massof, 2007).

The Rasch model is an item response theory model, a paradigm for the analysis and scoring of questionnaires that can be used to produce interval level data from ordinal responses, addressing many of the criticisms of summated scoring discussed above. The Rasch model is a probabilistic logistic model where items and respondents are scaled according to responses to a group of items (Rasch, 1993; Reise & Henson, 2003). The underlying construct being assessed is used to define the relative difficulty of each item. On the same linear scale of the construct, respondents are ordered from least to most ability, and items are ordered from most to least difficult.

Rasch analysis derives person and item measures in logits from raw ordinal data. Logits are the scale units (log odds units) in Rasch measuremnt. Person measures are an estimate of a person's underlying ability based on their performance on a set of items that measure a single trait. The item measure is the Rasch estimate of item difficulty.

Output of the analysis also includes the person separation, which indicates how well individuals can be reliably ordered by the instrument in terms of their level of perceived ability. The minimum acceptable value is considered as 2 (Pesudovs et al., 2007; Latham et al., 2015a). Item separation indicates how reliably items can be ordered in terms of their difficulty, with a minimum acceptable value considered as 3 (Latham et al., 2015a). Targeting is the difference between mean item and person measures, and a value of ≤1.0 logits suggests the items on the testing instrument match the range of the test candidates' proficiency (Gothwal et al., 2009; Latham et al., 2015a). Person-item maps help identify the relative targeting of item difficulties compared to person measures. An example of a person-item map for a 11 item instrument is provided in Figure 2.1.

The ability of an instrument to measure a single latent construct (unidimensionality) can be evaluated by Rasch based principal component analysis (Smith et al., 2002; Gothwal et al., 2010). In an instrument that is unidimensional, any selection of items graded by the respondent will assess the instrument's underlying trait, and therefore will provide a similar Rasch derived person measure. The instrument is considered to demonstrate reasonable unidimensionality if ≥60% of variance can be explained by the primary measure (Linacre, 2010a; Gothwal et al., 2012).

The difference between expected and observed scores is represented by fit statistics, and this provides further consideration of how well the items fit a unidimensional construct. A mean-square infit and outfit of 1 represent expected fit of an item to the Rasch model. Values less than one indicate overfit, where observations contain less variation than expected by the model, and suggest that the item is not contributing usefully to the scale. Values greater than one indicate misfit, where observations contain more variation than expected, and suggest that items are measuring something other than the proposed Rasch model. Acceptable mean square fit statistics include items with infits and outfits within the range of 0.5 to 1.5 mean square. These items are considered to show adequate fit (Linacre, 2014). Items with a fit of between 1.5 and 2.0 may not add much extra information to the scale, but also do not damage the scale (Linacre M., personal communication, 2015). Items with fits of greater than 2 should be considered for removal since they have the potential to damage the scale (Wright & Linacre, 2017).

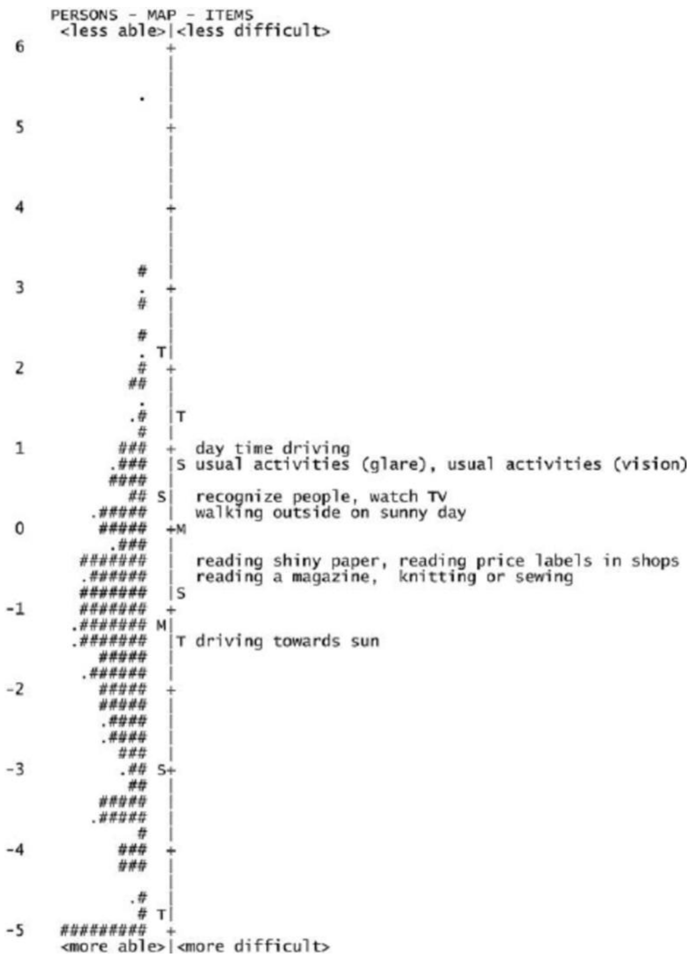


Figure 2.1 A person-item map for the 11-item Cataract TyPE Spec Questionnaire. 294 individuals waiting for cataract surgery are located on the left of the dashed line (each "#" represents two subjects), and more able subjects are located at the bottom of the map. Items are located on the right of the dashed line, and more difficult items are located at the bottom of the map. Taken from Gothwal et al., (2009).

2.4 Instruments

There are many patient reported outcome measures available (Rubin et al., 2001; Khadka et al., 2010; Massof, 2002), of which several might be suitable (de Haan et al., 2015) and sufficiently validated (Khadka et al., 2010) for use to represent the difficulties of people with visual field loss. Six of these instruments that have been used in studies to relate to functional visual field loss as outlined in (as outlined in Chapter 1) and therefore could be considered for use in this thesis, are reviewed below.

2.4.1 Visual Function Activity Limitation (VF 14)

Steinberg et al., (1994) developed the Visual Function Activity Limitation instrument to evaluate perceived function in ADLs in patients with cataracts. The questionnaire has 18 items regarding 14 vision dependent activities. Patients are asked to grade difficulty of tasks on a 5 point scale ranging from “4=no difficulty” and “0=unable to perform”. Tasks that are not applicable to respondents are recorded as missing data. The average score is multiplied by 25 to give an overall score ranging from 0 to 100. The 14 vision dependent activities include reading small print, recognising people when they are close, and seeing steps, stairs or kerbs.

The instrument was initially administered to 766 patients awaiting cataract surgery, and results are reported to correlate weakly with VA in the better eye (R^2=0.07), patients’ overall self-assessment of visual difficulty (R^2=0.20), and patients’ overall satisfaction with current vision (R^2=0.12) (Steinberg et al., 1994). Since then the instrument has been found to be a valid measure of functional visual impairment in patients with glaucoma (Parrish et al., 1997), candidates for a corneal graft (Boisjoly et al., 1998), patients with retinal disease (Linder et al., 1999), patients awaiting/undergone penetrating keratoplasty for keratoconus (Brahma et al., 2000), patients with exudative macular degeneration (Riusala et al., 2003), in children with nystagmus (Pilling et al., 2005), and patients with amblyopia and strabismus (Sabri et al., 2006).

In ordinal analysis, the VF-14 instrument has been shown to relate to visual function measures in a range of patients. Brahma et al., (2000) report a correlation between the overall VF-14 score and visual acuity (R^2=0.37), and the visual field (R^2=0.39) in patients who had undergone penetrating keratoplasty for keratoconus. A weaker relationship was also reported with contrast sensitivity (R^2=0.08). Riusala et al., (2003) report a stronger relationship between visual acuity (R^2=0.64) and contrast sensitivity (R^2=0.36) and the VF-14 score in patients with exudative macular degeneration. The visual field relates to overall VF-14 score in patients with glaucoma (R^2=0.34) (Parrish et al., 1997). Overall VF-14 score also correlates with visual acuity in candidates for corneal graft (R^2=0.28) (Boisjoly et al., 1998), and in patients with retinal disease (R^2=0.20) (Linder et al., 1999).

Valderas et al., (2004) used Rasch analysis to analyse the performance of the VF-14 in patients waiting for cataract surgery, and the instrument was found to be unidimensional. Another Rasch analysis using a sample of patients with mixed low vision suggested that the instrument does not have a range of items to assess the impact of visual impairment across a range of vision loss (Lamoureux et al., 2009).

The VF-14 is a simple and easy to administer questionnaire that has been shown to exhibit high internal consistency and is a reliable instrument that provides information not conveyed by clinical visual function measures. Although the instrument has been used in patients with a range of ocular pathologies, it was designed to measure functional impairment due to cataracts. The items in the questionnaire reflect this, and only 1 item out of 18 relates to mobility function. Since items in the instrument are biased towards reading and driving related activities, tasks commonly reported as difficulty by patients with cataracts, this questionnaire is not an appropriate instrument to use for the purpose of this study.

2.4.2 National Eye Institute Visual Function Questionnaire (NEI-VFQ)

The majority of instruments developed to assess function in patients with visual impairment ignore patients' abilities to emotionally and psychologically cope with their vision loss. The National Eye Institute (NEI) suggested the need for a general health related quality of life instrument that could be used to assess patients with a wide range of ocular disease and visual impairment, and developed the NEI-VFQ (Mangione et al., 1998a; 1998b). This instrument consists of 51 items that were compiled after focus groups with patients with a wide range of ocular disease, under 13 domains. Patients are required to answer questions on difficulty of activities and frequency of undertaking activities. The instrument was classically validated in groups of patients with diabetic retinopathy, age-related macular degeneration, glaucoma, cataracts, mixed low vision, and visual normals (Mangione et al., 1992).

Numerous studies have attempted to reduce the time it takes to administer the NEI-VFQ (approx. 15 minutes) by reducing the number of items (Mangione et al., 1992; Sloane et al., 1992; Javitt et al., 1993; Steinburg et al., 1994). These amended instruments vary in length from 14 to 31 items, but assess visual function without capturing the influence of emotional wellbeing and social functioning on visual disability (Mangione et al., 2001). Recognising the need for a shorter and more clinically appropriate version of vision targeted surveys that does not ignore patients' abilities to emotionally and psychologically cope with their vision loss, Mangione et al., (2001) developed the National Eye Institute 25-item Visual Function

Questionnaire (NEI-VFQ-25). This 25 item instrument, like the original 51 item NEI-VFQ, preserves the multidimensional content, but taking approximately 5 minutes to conduct, is more feasible in a clinical setting. This new instrument was evaluated in a mixed sample of patients with age related macular degeneration, primary open angle glaucoma, diabetic retinopathy, and cytomegalovirus retinopathy, and reliability was found to be comparable to the original 51-item instrument. (Magnione et al., 2001).

The use of the NEI-VFQ-25 has been demonstrated to be an accurate measure of vision targeted function in ordinal analysis in a sample of mixed low vision patients (Stelmack et al., 2001; 2002; Yanagisawa et al., 2012), patients with dry eye (Nichols et al., 2002), age related macular degeneration (Brody et al., 2001; Cahill et al., 2005; Revicki et al., 2010; Orr et al., 2011), age related eye disease including AMD and cataract (Clemons et al., 2003), glaucoma (Jampel et al., 2002a; 2002b; Ringsdorf et al., 2006; McKean-Cowdin et al., 2008; Lee et al., 2013), RP (Sugawara et al., 2009), branch retinal vein occlusion (Awdeh et al., 2010), diabetic macula oedema (Hariprasad et al., 2008), and uveitis (Schiffman et al., 2001).

In a Rasch analysis of this instrument Marella et al., (2009) found evidence of multidimensionality. Labiris et al., (2008) also report that while classical validation methods indicate the NEI-VFQ-25 is a valid and reliable instrument for assessing visual related quality of life, Rasch analysis indicates significant misfits, and results and subscales should be interpreted with extreme caution.

Perceived visual function assessment with this instrument has been shown to relate to visual field loss in patients with peripheral field loss. In glaucoma patients Jampel et al., (2002a; 2002b) report moderate correlations between visual field measures and the NEI-VFQ-25 (R^2=0.10-0.23) similar to those reported by Lee et al., (2012) (R^2=0.16), Rinsdorf et al., (2006)

(R^2=0.00-0.12), and McKean-Cowdin et al., (2007) (R^2=0.28). The NEI-VFQ-25 is also reported to relate to visual field measures in patients with RP (R^2=0.27) (Sugawara et al., 2009).

In patients with macular degeneration, overall NEI-VFQ-25 score correlates with visual acuity (R^2= 0.03-0.46) (Brody et al., 2001; Cahill et al., 2005; Revicki et al., 2010; Orr et al., 2011), near visual acuity (R^2=0.03-0.18) (Cahill et al., 2005) and reading speed (R^2=0.25) (Brody et al., 2001). The instrument relates to visual acuity measures in other samples, including patients with branch retinal vein occlusions (R^2=0.42) (Awden et al., 2010), and those with mixed age related disease (R^2=0.01-0.38) (Clemons et al., 2003).

The NEI-VFQ-25 was developed to provide a self-reported measure of visual function of patients with visual impairment, and has been shown to be a useful instrument for measuring visual difficulties in samples of varying causes and levels of visual impairment. However concerns have been noted regarding the validity of domains in the instrument, and regarding the range of measurement (Massof & Fletcher, 2001). Of the 25 vision targeted questions in instrument, only 10 relate to specific ADL; the remaining items assess health and vision related vision related quality of life. For these reasons the NEI-VFQ-25 is not the most appropriate instrument to use in order to assess the functional consequences of peripheral visual field loss.

2.4.3 Glaucoma Quality of Life Questionnaire (GQL-15)

The Glaucoma Quality of Life Questionnaire is a 15 item instrument that assesses the perceived disability that results from binocular visual field loss (Nelson et al., 2003). The instrument has been demonstrated to be effective at reflecting difficulties in ADL (Spaeth et al., 2006), and is used in several studies to assess the effect of binocular visual field loss on vision related quality of life (Nelson et al., 2003; Skalicky & Goldberg, 2008; Goldberg et al., 2009; Zhou et al., 2013). The GQL-15 instrument has been shown to relate to visual function measures including visual acuity (R^2=0.03-0.30) (Nelson et al., 2003; Goldberg et al., 2009; Zhou et al., 2013; Lee et al., 2014), contrast sensitivity (R^2=0.46) (Nelson et al., 2003) and visual field (R^2=0.09-0.26) (Nelson et al., 2003; Goldberg et al., 2009; Zhou et al., 2013; Lee et al., 2014).

The items contained in the GQL-15 questionnaire are significantly associated with visual field loss (Nelson et al., 2003). Despite the relevance of the 15 items to peripheral vision loss and mobility function, the instrument has been shown to be ineffective at distinguishing between individuals with moderate and severe visual field loss (Nelson et al., 2003). A more comprehensive instrument may be more sensitive to levels of visual field loss, and for this reason the GQL-15 has not been considered for use in this study.

2.4.4 Independent Mobility Questionnaire (IMQ)

The Independent Mobility Questionnaire was developed by Turano et al., (1999). Identifying the need for a mobility specific instrument that could be validated in patients with peripheral visual field loss, Turano et al., (1999) developed the questionnaire to determine difficulty across a range of mobility situations in order to measure perceived ability for independent mobility. The questionnaire comprises two parts: 35 items of mobility situations (part 1), and a series of questions requiring binary responses including questions regarding mobility related behaviour, fall history, and history of mobility training (part 2).

Several studies have related the IMQ with clinical measures of visual function. In patients with glaucoma the instrument is reported to correlate with visual acuity (R^2=0.05) and visual field measures (R^2=0.10) (Turano et al., 2002). Similarly in a study of patients with RP the IMQ related to visual acuity (R^2=0.04), contrast sensitivity (R^2=0.30) and the visual field (R^2=0.27) (Turano et al., 1999). Bibby et al., (2007) demonstrated relationships between visual acuity (R^2=0.17) and visual field measures (R^2=0.58) in a sample of mixed low vision patients.

The IMQ has also been used to assess the effectiveness of training and device interventions including peripheral prism glasses for hemianopia (Giorgi et al., 2009), Trifield prism visual aids (Wood et al., 2010), compensatory scanning training (de Haan et al., 2016), the ITT Night Vision Viewer, and Wide Angle Mobility Lamp (Mancil et al., 2005), and night vision goggles (Hartong & Kooijman, 2006).

The IMQ has been demonstrated to be well constructed, with high reliability for assessing perceived visual ability for independent mobility in Rasch analysis in patients with RP (Turano et al., 1999; Fenwick et al., 2016), glaucoma (Turano et al., 2002), and a heterogeneous sample of low vision patients (Bibby et al., 2007). The IMQ is a potentially good instrument to assess perceived mobility function, but fails to assess ADL not relating to mobility.

2.4.5 Activity Inventory (AI)

The Activity Inventory is an adaptive visual function questionnaire consisting of 459 tasks nested under 50 goals that are in turn nested under 3 objectives (Massof et al., 2007). Originally derived to assess low vision rehabilitation (Massof, 1995), the instrument structures ADL hierarchically to reflect the WHO classification for disease and functional consequences (Massof, 1998). The AI has been validated using Rasch analysis in a large heterogenous visually impaired sample (n=1880) (Massof et al., 2005a; 2005b; 2007).

The AI contains a wide spectrum of activities that were chosen to represent the visual abilities of a mixed visually impaired population. A specific task such as "fastening zippers, clasps or hooks" is performed to achieve the goal "dressing", which is nested under the objective of "daily living". A patient experiencing functional limitations cannot perform specific tasks, but a disability is experienced only if relevant goals cannot be achieved (Massof et al., 1995; 2005a). Therefore, the instrument rates the importance of each goal on a four point scale (0-not important, to 3-very important). If the goal is important, the difficulty caused by visual impairment is rated on a five point scale (0-not difficult to 4-impossible). Only goals that are important and difficult are fully assessed at task level (Massof et al., 2005b). The instrument minimises item irrelevancy, therefore reducing administration burden by utilising adaptive testing.

Vision related activity limitation assessed using the AI has been demonstrated to relate to clinical visual function measures, including visual acuity (Tabrett & Latham, 2011) and binocular visual field loss (Tabrett & Latham, 2012).

2.4.6 Dutch Activity Inventory (D-AI)

Intending to develop an instrument that systemically assesses rehabilitation needs, Bruijning et al., (2010) created a new Dutch version of the AI in which goals are classified by the "Activity and Participation" domains of the World Health Organization International Classification of Functioning, Disability and Health (World Health Organization, 2013). Considering also the cultural applicability of certain activities to a European context, Bruijning et al., (2010) made some rearrangements to the original instrument. One example of an amendment is the task of riding a bike. While in the AI this activity was assigned merely to an "outdoor activity", since riding a bike is a common mode of transport in the Netherlands, the item was nested under a more appropriate goal of mobility. A further alteration to the instrument was the addition of a tenth domain that is not included in the "Activities and Participation" of the ICF (World Health Organization, 2013); "coping with mental (emotional) health aspects". Focus group discussions asserted the importance of considering these topics in rehabilitation outcomes. Compared with the original AI, more goals were added relating to mobility, employment, education, and interpersonal interactions, and subgoals relating to specific hobbies were removed (Bruijning et al., 2013).

The final D-AI consists of sixty five goals nested under 10 domains. Underlying these goals are 959 tasks. Firstly, the instrument scores self-reported importance of goals on a four point scale (0-not important to 3-very important). If the goal is of at least some importance (score >0), patients are asked to score perceived difficulty of the goals on a five point scale (0-not difficult to 4-impossible). A priority score is then calculated by multiplying goal importance and difficulty, so that all goals are ranked to create a "top priority' list. In the second half of the administration of the instrument, tasks underlying the top fifteen priority scores are assessed with the same difficulty scale (Bruijning et al., 2010).

The instrument has been analysed at goal level using Rasch analysis in people with RP (Latham et al., 2015a). This demonstrated that the D-AI at goal level performs well as an instrument assessing perceived ability with ADL. In this study, the specific daily living goals that were reported most difficult were mobility outdoors, shopping, physical activity/sport, mobility indoors and using public transport. As expected from a questionnaire that examines a wide spectrum of rehabilitation needs however, the instrument's unidimensionality is not perfect. In this evaluation, Latham et al., (2015a) found that responses to goals underlying "coping with mental (emotional) health aspects" domain were not consistent with the remainder of goals that related to ADL, and therefore did not support the D-AI's unidimensionality. The difficulty of tasks associated with emotional health in patients with RP was assessed in another study (Latham et al., 2015b). Despite the domain not supporting the instrument's unidimensionality, it was found to be a valid separate tool in assessing the emotional difficulties arising from visual loss in patients with RP.

In a further study by Latham et al., (2017) the difficulty of tasks underpinning the most difficult goals of the D-AI for people with RP were investigated. The most difficult of these tasks were orienting in poor light and avoiding peripheral obstacles. While these tasks were reported more difficult by people who had greater visual loss (as indicated by visual impairment registration status), those who used mobility aids (cane or guide dog) perceived less difficulty with these activities than those who did not.

The D-AI provides a comprehensive item bank that has been used in individuals with peripheral visual impairment (Latham et al., 2015a). At goal level the instrument performs well at assessing perceived ability with ADL. For these reasons, the D-AI will be used in this study as the outcome measure assessing perceived visual function. Since responses to goals underlying the "coping with mental (emotional) health aspects" domain were not consistent with the remainder of goals that related to ADL (Latham et al., 2015a), these goals will not be assessed.

2.5 Falls

Beyond general activity limitation, one specific area of function that is particularly relevant in terms of mobility is falls. Falls are a common occurrence, with one third of community dwelling elderly adults having at least one fall a year (Blake et al., 1988; Tinetti et al., 1988). The consequences of falls are well documented and include hospital admissions (Sattin et al., 1990), nursing home admissions (Sattin et al., 1990; Tinetti & Williams, 1997), and death (Sattin et al., 1990; Campbell et al., 1990).

The factors associated with the risk of falling are also well documented and include reduced activity level (Vellas et al., 1987; Campbell et al., 1989; King & Tinetti, 1995; Friedman et al., 2002; Lamoureux et al., 2010; Schepens et al., 2012), musculo skeletal disorders (Campbell et al., 1989; Friedman et al., 2002), polypharmacy (Campbell et al., 1989; Chang & Do, 2015), the use of mobility aids (Arfken et al., 1994), female gender (Kressig et al., 2001; Stevens et al., 2006), old age (Chang & Do 2015), and visual impairment (Jack et al., 1995; Ivers et al., 1998; Klein et al., 1998; Lord & Dayhew, 2001; Klein et al., 2003; Coleman et al., 2004).

2.5.1 Relationship between visual function and the risk of falling

Reduced visual acuity (Ivers et al., 1998; Jack et al., 1995; Klein et al., 1998; 2003; Coleman et al., 2004), contrast sensitivity (Ivers et al., 1998; Klein et al., 1998; Lord & Dayhew, 2001), and depth perception (Lord & Dayhew, 2001) have all been association with an increased risk of falling.

Visual field loss, assessed in a range of strategies, is also significantly associated with an increased risk of falling in patients with glaucoma (Black et al., 2008; 2011; Ramulu et al., 2012; Baig et al., 2016), and samples of mixed low vision patients or the elderly (Jack et al., 1995; Ivers et al., 1998; Klein et al., 1998; Ramrattan et al., 2001; Freeman et al., 2007; Patino et al., 2010).

Some studies have suggested greater correlations between specific field areas and fall history. Patino et al., (2010) suggest that central vision loss alone is a poor predictor of the rate of falls, and that visual field loss in both the central and peripheral visual field independently increase the risk of falling. Freeman et al., (2007) also suggest that losses in the peripheral visual field (20-60 deg) are a more important risk factor for falling than the central visual field (0-20 deg).

2.5.2 Collection of falls data

The majority of studies investigating the relationship between visual function and the risk of falling use retrospective collection of falls data; the majority of which ask participants to report if they fallen or how many falls have occurred in the previous 12 months (Ivers et al., 1998; Klein et al., 1998; Ramrattan et al., 2001; Black et al., 2008; Patino et al., 2010; Baig et al., 2016). Cummings et al., (1988), however, report that falls among the elderly are often forgotten, and therefore there is likely to be an underreporting of falls in clinical settings. They suggest helping the patient to place a fall in a specific period of time by asking about fall history since a memorable event to improve the accuracy of the recall. Other studies have used prospective collecting of falls data (Freeman et al., 2007; Black et al., 2011), and therefore reduce the risk of forgetting falls.

Since it is not possible to collect data prospectively in this study, the number of falls participants report in the previous 12 months will be recorded. This provides an easy to collate measure of falls, which has been shown to relate to visual function assessment in numerous studies (Ivers et al., 1998; Klein et al., 1998; Ramrattan et al., 2001; Black et al., 2008; Patino et al., 2010; Baig et al., 2016).

2.6 Performance based assessment

In comparison to self-report instruments, performance based assessments provide objective measures of patients' functional status. Performance based assessments of potential relevance in this thesis include walking speed, orientation accuracy, and time to complete tasks.

2.6.1 Mobility performance

There is no standard method for assessing orientation and mobility performance. Consequently, studies that conduct mobility performance based assessments often develop their own mobility courses to evaluate mobility function. As a result of this lack of uniformity, the findings of studies that assess mobility performance are difficult to compare.

There are, however, traditional measures of scoring mobility performance that include travel time, and the number of mobility incidents (bumps, stumbles, orientation errors). Individuals with visual impairment will slow down in unfamiliar or more difficult to orientate areas (Clark-Carter et al., 1986), and the time taken to complete a mobility course relates to the confidence of the subject (Black et al., 1997). Therefore, the reliability of time scores is improved by expressing the time taken to complete a mobility course as a percentage of preferred walking speed (Haymes et al., 1994). This is a measure of a subject's walking speed along an unobstructed pathway. By accounting for variations in ages and the physical attributes of the subjects, this measure allows for more valid inter-subject comparisons (Haymes et al., 1994). How safely a subject is able to navigate a mobility course can be represented by the number of errors made along the course (Black et al., 1997). Errors have been defined as contact with obstacles (Marron & Bailey, 1982), strays from marked pathways (Alfano & Michel, 1990), and incidents including stumbles and orientation errors (Turano et al., 1999).

Both indoor and outdoor courses have been used to assess mobility performance. While outdoor courses provide real world conditions because of the wide variations in contrasts, spatial frequencies and natural terrain, these variables are difficult to control and measure (Brown & Brabyn, 1987). Indoor courses are simple, safe, convenient, and allow control over variables such as illumination (Black et al., 1997), and are used more commonly in studies of assessment-based mobility performance. Some courses use a long straight corridor (Marron & Bailey, 1982; Geruschat et al., 1998; Kuyk et al., 1998; Turano et al., 1999; Hassan et al., 2002; Lovie-Kitchin et al., 1990), while others require subjects to follow more circuitous paths (Marron & Bailey, 1982; Kuyk et al., 1998; Soong et al., 2001; Turano et al., 2004; Lovie-Kitchin et al., 2010). Courses vary in difficulty with a varying number and type of obstacles, the use of pedestrians and stairs, and illumination. Since walking speed alone does not fully describe a subject's mobility ability (Turano et al., 2004), Lovie-Kitchin et al., (1990) suggest that the use of obstacles allows a greater range of error scores to represent variations in mobility performance.

Marron & Bailey (1982) utilised both an indoor and outdoor mobility course to assess mobility performance. The first course was a long corridor with poor contrast between floor and wall and with paper cylinders suspended from the ceiling, and the second course was undertaken outside and included obstacles that varied in spatial detail and contrast. In the sample group of mixed low vision subjects, the number of errors (contact with obstacles, and the time it took for subjects to reorient independently after a contact with an obstacle) was found to relate to contrast sensitivity (R^2=0.32) and visual field (R^2=0.30) measures, but not visual acuity (R^2=0.01).

Turano et al., (1999) also used two mobility courses to assess mobility ability in patients with glaucoma. Both courses were 29m long indoor paths, with and without obstacles including chairs, tables, and turns. The time required to complete the courses, and the number of mobility incidents (bumps, stumbles, and orientation incidents) were found to correlate similarly to visual acuity (R^2=0.12-0.20), contrast sensitivity (R^2=0.17-0.25), and visual field (R^2=0.15-0.18) measures for both mobility courses.

In samples of people with RP, visual function, including visual field loss, correlates with walking speed and errors on indoor mobility courses (Geruschat et al., 1998) and outdoor courses (Haymes et al., 1996) that vary in difficulty.

Similarly in a sample of people with mixed visual impairments, Lovie-Kitchin et al., (1990) report a relationship between visual field measures and the time taken and number of errors made on a 79m indoor mobility course with 87 obstacles (R^2=0.30-0.58). In another study by Lovie-Kitchin et al., (2010) an indoor 20m corridor, and a 79m indoor course with high obstacle density were used to assess the mobility function of a mixed low vision sample. The visual field measures were found to relate to time and error scores (R^2=0.43-0.45).

Mobility courses have also been used to assess mobility function in older adults. Turano et al., (2004) used a 16.4m circuitous course with obstacles that included hanging plants, waste baskets, and wooden life sized people. They report loss of visual field results in a decrease in walking speed and increase in the number of obstacle collisions, but no change in the frequency of orientation errors (defined as a departure from the specified path).

Other assessments of mobility performance have been used to determine mobility function. One such assessment is "The Timed Up and Go" test (Podsiadlo & Richardson, 1991). This test of basic functional mobility involves observing and timing the patient while they rise from an arm chair, walk three metres, turn, walk back and sit down again. Studies suggest that this assessment is a reliable method of quantifying functional mobility (Podsiadlo & Richardson, 1991) and identifying patients that are at risk of falls (Okumiya et al., 1998; Shumway-Cook et al., 2000; Kristensen et al., 2007). Laboratory tests of motor abilities such as balance and gait speed have also been used to determine mobility function (Larish et al., 1988; Berg et al., 1989).

2.6.2 Assessment of activities of daily living

The Melbourne Low-Vision ADL Index (Haymes et al., 2001) is a test of activities of daily living appropriate for patients with low vision. A desk based assessment comprises 18 observed items including writing a bank cheque, telling the time using a wrist watch, and threading a needle. A further nine items are assessed with a self-reported questionnaire. The instrument is reported to be a valid and reliable standardised assessment of ADL performance in mixed low vision patients (Haymes et al., 2001), and correlates with clinical visual function measures (R^2=0.31) (Haymes et al., 2002).

2.7 Summary

In order to determine the functional abilities of individuals with visual impairment, visual function assessment questionnaires or performance-based assessments must be used. Functional ability is intertwined with other factors including general health status and psychological and social well-being (Feinstein et al., 1986), intellectual capacity or even pride (Rubenstein et al., 1984), and this makes measurement of self-reported function difficult (Kane & Kane 1981).

Self-reported function is particularly influenced by additional psychosocial factors. Depression in particular is reported to relate to perceived difficulty in ADL in patients with vision loss (Haymes et al., 1996; Tabrett & Latham, 2011), and may be a stronger predictor of self-reported function than visual acuity (Shmuely-Dulitzki et al., 1995). Poor adjustment to visual loss is also reported to predict self-reported visual function (Reinhardt 2001; Tabrett & Latham, 2012). Wahl et al., (2003) and Cimarolli & Boerner (2005) suggest that social support from family and friends may be the most important type of support for patients with visual impairment. Such factors may account for different perceived functional abilities being reported by two patients with similar degrees of visual impairment (Lowe & Drasdo, 1992).

Denniston et al., (2014) suggest that the development of patient reported outcome measures in ophthalmic research has been driven by the recognition that clinical tests imperfectly capture the extent to which patients are impacted by visual impairment. Despite the subjective nature of self-report, and a significant degree of unexplained variance in perceived function being accounted for by the psychosocial factors discussed above, self-report may be the only way for individuals to communicate what happens outside a clinical encounter. In a report on patient centred care by Nelson et al., (2015) it was suggested patient reported outcome measures are an effective method of collecting crucial information such as perceived needs, symptoms, and function, and have the potential of bridging the gap between clinical tests and the patient world.

Solutions to functional difficulties must acknowledge non-clinical factors and be tailored to each patient. Massof (1998) suggests in defining disability, besides perceived difficulty, we must consider the importance of the task, as well as the intended goals of certain activities. He reports an example of a patient who demonstrated good reading ability with an electronic vision aid, although on later visits the patient admitted to having substituted reading a newspaper with listening to the radio. The patient explained that her intended goal was not just to read a newspaper every morning, but to be able to learn the news in a relaxing and meditative way, while curled up on a sofa in a sun room drinking coffee. The ability to complete a task successfully, or in a certain time may not equate to the patient's perception of ease. It is therefore important to consider the value that the patient places on goals, and how difficult the patient perceives achieving the goal to be (Massof, 1998), both of which are not obtained in performance based assessments.

While some studies report discrepancies between self-reported and measured function (Linn et al., 1980; Elam et al., 1991; Dorevitch et al., 1992; Friedman et al., 1999; Latham & Usherwood, 2010), Szlyk et al., (2001) found that perceived functional ability is correlated with actual performance of ADL in individuals with RP. They report statistically significant correlation between thirty out of thirty two functional assessment and questionnaire items.

They suggest that correlations between perceived and measured function is stronger for items that lent themselves to a more straightforward assessment such as "reading", compared with items that were more multidimensional such as "using a directory in a shopping mall". However, since few ADL are not multidimensional, self-reported function could be a more effective method of determining functional ability of patients with visual impairment. Stucki et al., (2007) report that understanding the relationship between functional difficulties, psychosocial factors, and environmental factors is necessary to successful rehabilitation.

To determine whether discrepancies exist between perceived and actual reading function, Friedman et al., (1999) examined the relationship between self-reported and observed reading ability in a population sample of elderly adults. They report discrepancy between perceived and measured reading performance. A portion of patients in their sample reported minimal or no difficulty with reading a newspaper and yet do not read at a rate that is consistent with sustained reading. Freidman et al., (1999) suggest that there could be a period of decline in reading performance measures before reading ability is perceived by a patient as difficult. Compensatory strategies adopted during this period, termed preclinical disability (Fried et al., 1991; Fried et al., 1996) could explain why some patients do not perceive difficulty despite compromised reading performance. There were also patients who reported extreme difficulty reading and yet were able to read at an acceptable rate. This discrepancy may be based on underlying expectations and education.

Assessing performance on a mobility course provides an objective measure of "real world" mobility function. Although these objective measures do not completely capture the extent to which patients are impacted by visual impairment, it has been suggested that performance based mobility measures are more valid, reproducible, sensitive to change, and applicable to cross-cultural studies when compared to self-reported measures (Guralnik et al., 1989; Reuben & Siu, 1990). Furthermore, Rozzini et al., (1997) suggests that performance based measures may detect functional limitation before it becomes measurable by self-reported measures.

However, while performance based assessments are considered objective measures of function, and may be assumed to be more effective at quantifying functional ability, it could argued that measurements of performance still require patients' cooperation and results will depend on patients' motivation (Massof & Rubin, 2001). In a low vision clinical setting, declines in visual function are often screened for by asking patients to report difficulties with particular tasks, and perceived functional difficulties are most likely used as an indicator of functional ability than assessed performance. Berson (1993) suggests that considering ability in specific mobility situations is important in establishing a relationship between function and disease state. Using patient reported instruments allows for the determination of functional ability across a wide range of tasks and situations, unlike performance based assessments where only ability in limited tasks and conditions can be measured. Performance exhibited during a performance based assessment usually reflects the maximal performance in an artificial set up (Coman & Richardson, 2006).

Another limitation of performance based assessment is the difficulty in developing instruments. Environmental factors such as lighting levels, the number of obstacles on a mobility course, and the general complexity of an environment (Long et al., 1990; Black et al., 1997; Kuyk et al., 1998) make it difficult to standardise such assessments. Furthermore, these variations may render a task environmentally invalid or not representative of a real-life situation patients encounter (Leat & Lovie-Kitchin, 2006). There are also practical difficulties in developing these instruments as Leat & Lovie-Kitchin (2006) demonstrate. They review the most common methods of measuring and scoring orientation and mobility performance and report the difficulty in finding an appropriate space to conduct the assessment, setting up the most appropriate level of complexity, and controlling and recording lighting conditions in outdoor assessments.

Therefore, while self-report instruments are known to be influenced by additional factors, they can take into account the relevance of particular tasks, and can assess a wide range of activities. Objective measures of mobility performance can lack validity and reproducibility, and provide evidence of only the specific capabilities measured. Therefore, for the purposes of reflecting functional ability in general, self-report methods rather than objective assessment are used in this thesis for comparison to visual field function.

2.8 Aim of thesis

Optometrists often encounter patients with peripheral visual field loss. As outlined in Chapter 1, restricted visual fields have significant effects on the ability to undertake visual tasks and on mobility, and is one of the most significant risk factors associated with falling (Chapter 2). The purpose of current approaches to the visual field assessment are to detect and monitor the progression of ocular and neurological pathology. There is no visual field test currently available that is optimised for determining the functional consequences of visual field loss. This patient centred study aims to determine the most appropriate methods to assess peripheral functional visual fields in low vision patients.

Approximately fifty participants are recruited for both Experiment 1 and 2. The sample size is based on the clinical function predictor variables that will be considered in the regression equations. Since it is known that a minimum of 10 participants per predictor variable is appropriate (Van Voorhis & Morgan, 2007), 5 clinical function variables are entered into all regression analyses. This number of participants also reflects the sample size used in similar studies (Turano et al., 1999; Bibby et al., 2007; Lee et al., 2013). Participants with a wide range of visual field loss.

The visual field techniques outlined in Chapter 1 will be utilised and results compared to self-reported function using instruments outlined in Chapter 2. Regions of the visual field are related to self-reported function to determine the locations of the visual field which best reflect self-reported vision related difficulties in Experiment 1. In the second experiment, different visual field paradigms are used to assess these locations, and are compared to determine which methods of assessment are most reflective of perceived real-world function, and are more clinically acceptable to patients and have potential to be useful to clinicians.

Chapter 3

Experiment 1: Visual Field Areas

3.1 Introduction

While the association between visual fields and functional ability in individuals with visual impairment is well documented as outlined in Chapter 1 and 2, the significance of visual field regions beyond 30 degrees to reflect functional visual difficulty is unclear. Binocular functional fields have been reliably assessed in patients with visual impairment by implementing commonly used monocular central threshold static perimetry test programs, namely the central 24-2 and 30-2 tests, binocularly (Chapter 1). This method of assessment is used in this experiment with the aim of determining locations within the visual field out to 60 degrees eccentricity that best reflect functional difficulty with peripheral field loss and should be considered in a functional field assessment.

3.2 Methods

3.2.1 Participants

The study was carried out at Anglia Ruskin University Eye Clinic where suitable participants who had previously been seen at the clinic and consented to being contacted regarding research studies were invited to participate. A number of charities including RP Fighting Blindness and the International Glaucoma Association were also contacted to advertise the study on their social media pages and newsletters. Fifty two participants with general peripheral field loss, for example due to pathologies such as glaucoma and retinitis pigmentosa were recruited. To restrict the potential effects of a roving ring or jack in the box scotoma, participants with a distance hyperopic correction of > +5.00DS were excluded from the study (Lachenmayr et al., 1992; Mandaya et al., 1992). Individuals with conditions that do not primarily affect peripheral visual function, such as AMD, were excluded from the study, along with those under 18 years old and those unable to perform verbal evaluations in English. Ethics approval was granted by Anglia Ruskin University Research Ethics committee. All participants gave informed consent after the nature of the study was explained.

3.2.2 Demographics

A series of structured demographic questions conducted in a face to face interview elicited key information including age, gender, cause of visual impairment, length of time since ocular diagnosis, the stability of the condition, ongoing hospital monitoring or treatment, registration status, living arrangements, and current education or employment status. The presence of any comorbid conditions from a list of 12 common medical conditions as described by van Nispen et al., (2008) were recorded and used to represent general health (Appendix 1.1). It has been suggested that using a pre-structured response option can reduce the risk of under representing co-morbidity associated with self-report (van Nispen et al., 2008). Similar lists were used in other related studies (Brody et al., 2001; Jang et al., 2001; Freeman et al., 2007; Brorkman et al., 2008). Details of any prescribed medication were also recorded.

The participants were also asked to report the number of falls, as defined in the Merck Manual (Merck et al., 2011), The Prevention of Falls Network for Dissemination (PRoFouND) and WHO, in the past 12 months. Lord et al., (2007) suggests that this simple definition is appropriate for studies requiring data where details of falls are unrecorded (routine surveillance data/accident records), or where a high proportion of subjects cannot provide reliable information about their falls.

3.2.3 Preliminary tests

Habitual spectacle correction was focimetered and recorded, along with the type of any low vision and mobility aids used. The participants' interpupillary distance was measured for a fixed distance of 30cm.

3.2.4 Visual acuity

High contrast visual acuity was assessed binocularly with participants' habitual spectacle correction using an internally illuminated 3m EDTRS chart that maintains chart luminance at 130cd/m^2. Visual acuity was measured on a letter per letter basis (Arditi & Cagnelloa, 1993) and scored as the number of letters correctly read and converted to LogMAR, according to the method recommended by Bailey et al., (1991). Each letter was given a value of 0.02 log units. Testing was administered from the top of the chart until no letters on a line could be correctly identified (Hazel & Elliott, 2002). The chart was positioned 3m from the participant. If the largest letters could not be read at 3m, the chart was moved 50% closer to the participant to

1.5m and, if necessary, 0.75m. Participants who failed to read any of the letters at 0.75m were assigned a score of 3.0 LogMAR (Myint et al., 2016).

3.2.5 Contrast sensitivity

Contrast sensitivity was measured binocularly with a Pelli-Robson Chart (Pelli et al., 1988) at 1m under controlled room illumination of approximately 100cd/m^2. Since it has been suggested that the recommended +0.75D addition commonly used to determine contrast sensitivity with the Pelli-Robson chart does not significantly influence results (Latham & Hughes, 2013), the test was administrated with the participant's habitual spectacle correction. Contrast sensitivity was scored as the number of letters read correctly, with each letter after the first triplet scoring 0.05 log units, until no letters of a triplet could be correctly identified (Elliott et al., 1991; Elliott & Bullimore, 1993; Arditi, 2005). Once the participant stated that they could no longer identify the letters, the next lower contrast triplet were indicated on the chart and the participant instructed to view them for 20 seconds. This was to achieve maximal contrast sensitivity (Elliott et al., 1991). Participants with no measurable CS function were assigned a score of 0.00LogCS (Myint et al., 2016).

3.2.6 Near reading performance

MNRead charts were used to determine clinical reading performance (Mansfield et al., 1993; Ahn et al., 1995). The test was administrated binocularly, with the MNRead chart positioned at 40cm. The participant's head rested on the back of the chair with the chart on an easel to ensure that the working distance was maintained during assessment. The chart luminance was approximately 80cd/m^2. The participant used their own habitual reading spectacles if corrected for 40cm. Otherwise the habitual distance correction was placed in a trial frame with an age appropriate reading correction for the required distance. If the participant was unable to read the largest sentence at 40cm, the chart was moved 8cm closer to the participant, to 32cm, 24cm, 16cm and 8cm. Participants unable to read any of the print at 8cm were assigned a reading acuity score of 3.0 LogMAR (Myint et al., 2016). Participants were instructed to read the test sentences aloud starting from the top of the chart, and to continue reading until they could not read any words in a sentence. Any words missed or read incorrectly were recorded on the score sheet. The reading acuity was determined using formula detailed in the manufacturer's instructions (Legge, 2010). The critical print size (CPS) was determined by inspecting the reading-speed plateau of the plot between reading speed versus print size. The maximum speed was calculated as the average reading speed for sentences in print larger than the CPS (Patel et al., 2011).

3.2.7 Binocular visual fields

Binocular visual field assessments were performed using the Humphrey Field Analyser utilising the monocular test strategy for the right eye. The standard size III Goldmann white target was used with all participants. An adaption to the fixation target that slotted into the fixation target hole was used where necessary to provide either a black 2mm high contrast pericentral ring around the fixation spot, or a black X shape with strokes of 2mm (Henson et al., 1998). The background luminance was 10cd/m^2.

The chin rest was positioned as far right as possible and the left hand side of the chin rest was used. Since implementing monocular tests binocularly using the HFA invalidates conventional methods of fixation monitoring (Heijl & Krakau, 1975), participant's fixation was monitored visually (Black et al., 1996; Leat & Lovie-Kitchin 2006; Tabrett & Latham, 2012). To ensure binocularity was maintained, and since it was only possible to monitor the fixation of the RE, participants were reminded to keep both eyes open throughout the assessment. They were also invited to request a rest break should they find themselves inclined to close their non-dominant eye. Fixation was observed by the practitioner and judged subjectively. Other reliability indices provided by the HFA, including false positives and false negatives, were also reviewed. The test was stopped if during the first attempt false negative or false positive responses exceeded 50%, or if poor fixation was observed by the practitioner. The participant was reinstructed and a new test was then started. The subsequent test attempt was not interrupted if poor reliability indices or poor fixation was observed. All cases were used in subsequent analyses.

The central 30-2 threshold test on the HFA was used to evaluate the binocular central visual field. The 30-2 assesses the visual field function of approximately the central 30 degrees around fixation with 76 points spaced every 6 degrees. The Swedish Interactive Threshold Algorithm (SITA) Fast test strategy was adopted (Bengtsson & Heijl, 1998; Wild et al., 1999). Full aperture trial lenses were used in adult half eye trial frames with lens centration distances corrected for near. The habitual distance vision prescription was corrected for near as recommended in HFA manual (ZEISS Global - Carl Zeiss, 2017). The peripheral 60-4 threshold test was then used, again adopting SITA Fast test strategy, to evaluate the binocular peripheral visual field. The 60-4 assesses the function of approximately the peripheral 30-60 degrees with 60 test points spaced every 12 degrees. In line with the HFA manual's instructions, the 60-4 test was performed uncorrected to minimise the possibility of lens and frame artefacts.

3.2.8 The Dutch Activity Inventory

The Dutch ICF Activity Inventory (Bruijning et al., 2010; 2013) was used to determine perceived difficulty in Activities of Daily Living. The questionnaire was conducted as a structured face to face interview and participants were asked to grade their perceived level of function when undertaking each item on a 5 point scale. The original questionnaire assesses the difficulty of 47 rehabilitation goals, nested within 10 domains of the World Health Organization International Classification of Functioning framework. In the current study, the questionnaire was performed at goal level for 44 goals. These represented the 47 goals proposed by Bruijning et al., (2010) but excluded a goal underpinning the emotional health domain, and a further two relating to driving and riding a bike that have been shown not to fit the unidimensional construct of the questionnaire in people with peripheral vision loss (Latham et al., 2015a). While performing the entire questionnaire with the adaptive methods advised by its creators would have be an ideal, the extreme length of the entire questionnaire precludes its use for the purpose, which we required it (Wolffsohn et al., 2000). Completing the questionnaire at goal level reduced the response burden on the participant and facilitated efficient implementation (Ryan et al., 2008).

Four goals underlying the mobility domain in the D-AI were used to determine perceived difficulty in mobility related ADL (mobility in your own home, mobility indoors in unfamiliar surroundings, mobility outdoors, and using public transport). Underlying each goal in the D-

AI is a number of specific task questions relating to that goal. The difficulty of 12 mobility tasks were asked on the same 5 point Likert scale from tasks underlying goals of mobility indoors and outdoors.

3.3 Results

3.3.1 Statistical analysis

Univariate analyses were first conducted to explore the demographic, visual field, and other clinical visual function variables. To investigate the relationship between the predictor variables and self-reported function a series of analyses were undertaken. Mann-Whitney U tests were conducted for the dichotomous predictors to establish whether the means of the independent samples significantly differed. Kruskal-Wallis tests were performed on the nominal/categorical data as a non-parametric determination of differences between the independent groups. Linear correlation coefficient bivariate analyses were conducted to investigate the relationship between the continuous predictor variables and self-reported visual function. Two correlation coefficients exist: Pearson's and Spearman's. While both coefficients provide a standardised measure of strength of the relationship between two variables, Spearman's does not rely on the assumptions of a parametric test, or a normally distributed sample (Field, 2015), and so 2-tailed Spearman's rho correlations were performed, making no assumption to the normal distribution of the data.

To control the error rate when multiple significance tests are carried out, a more stringent significance level is required as suggested by the Bonferroni correction (Field, 2005). A criterion of significance of 0.05 divided by the number of tests conducted is used when multiple bivariate regressions are performed.

For the clinical visual function variables that significantly correlated with perceived function, multiple regression analyses were carried out. Since this part of the investigation is largely exploratory, the variables were entered into the regression model in a stepwise manner. This allowed the prediction of self-reported visual function by a linear combination of two or more predictor variables, and to explore the unique variance explained by each predictor variable (Field, 2005).

Cook's distance and Mahalanobis' distances were reviewed to determine if any an outlying case exerted undue influence on the regression model (Field, 2005). Cook's distances indicate the overall influence of a case on the regression model, and values greater than 1 may be a cause for concern (Cook & Weisberg, 1982). Mahalanobis' distances examine the distance of cases from the means of the predictor variables. Critical values depend on the number of predictors and the sample size (Barnett & Lewis, 1978). Unless specified otherwise, no case in any of the multiple regression models had a Cook's Distance of >1, suggesting none had an undue influence on the regression models, an assumption supported by Mahalanobis' distance values.

The Durbin-Watson statistic was determined to assess serial correlations between errors in the regression models and inform whether the assumption of independent errors was tenable. The size of the Durbin-Watson statistic depends on the number of predictors in the model and the number of observations. It has however been suggested that values less than 1, or greater than

3 are indicative of dependant errors, and are a cause for concern (Field, 2005). Unless otherwise indicated, the Durbin-Watson statistic was close to 2 for the analyses, supporting the presence of independent errors.

Multicollinearity occurs when two or more predictor variables in a regression analysis are highly correlated with each other and was investigated by studying the collinearity statistics of the regression models. Multicollinearity is suggested if variables have a correlation R^2 value of >0.81 (Pallant, 2001; Field, 2005). There is a strong correlation between the central (0-30 degrees) and the peripheral (30-60 degrees) visual field scores (R^2=0.85, p<0.001, 2-tailed Spearman's correlation coefficient). Although this may be indicative of a problematic level of multicollinearity, other measures were also considered to determine whether the central and peripheral visual field scores were independent. These measures included the tolerance and variance inflation factor statistics. Variance inflation factors (VIF) indicate the strength of the linear relationship between predictors. It has been suggested than if the largest VIF is greater than 10 then multicollinearity may be biasing the regression model (Myers, 1990; Bowermann & O'Connell, 1990; Field, 2005). An average VIF substantially greater than 1 is also indicative of the presence of multicollinearity (Bowermann & O'Connell, 1990). Tolerance statistics also measure multicollinearity and are the reciprocal of the VIF. Menard (1995) and O'Brien (2007) suggest that values below 0.1 indicate a multicollinearity bias. Collinearity statistics of our visual field explanatory variables discounted the presence of multicollinearity in all the analyses, with favourable variance inflation factors and tolerance statistics, suggesting that the regression models performed in all our analyses were not adversely affected by the strong intercorrelation. Furthermore it has been suggested that in the case that the predictor variables follow the same pattern of multicollinearity in new data as in the data in which the regression model is based, the presence of multicollinearity will not affect the efficacy of extrapolating our findings. (Gujarati & Porter, 2009). The predominant focus on multicollinearity in relation of the inflation of the variance of regression coefficients and the stability of regression analysis results has been contested by O'Brien (2007) and Goldberger (1991). O'Brien (2007) suggests that collinearity statistics must be placed into the context of the effects of other factors that could influence the variance of the regression coefficient.

The fit of each regression model to the data were assessed by reviewing the residuals. Homoscedasticity in the regression analysis is the assumption that the residuals of the predictor variables have similar variances (Field, 2005). The data must exhibit homoscedasticity and have independent and normally distributed residuals for the model to be generalizable. Plots of the standardised residuals against standardised predicted values were reviewed to determine the extent to which the variance of residuals was equal for all predicted values. For all our regression models unless indicated otherwise, residuals were not significantly different from normal, and exploration of the standardised residual against standardised predicted value plots supported the assumptions of homoscedasticity and linearity. The probability plots of regression standardised residuals also indicate a normal distribution.

Responses to the twelve mobility related activities from tasks underlying two goals from the mobility domain in the D-AI were not Rasch analysed but instead dichotomised and used in a receiver operating characteristic (ROC) analysis. Difficulty was compared to scores for different visual field areas to evaluate how effective they were at selecting participants with perceived mobility difficulty (sensitivity), and without perceived mobility difficulty (specificity) using MedCalc version 12.1.4.0 (MedCalc Software, Ostend, Belgiumusing).

3.3.2 Demographic variables

Table 3.1 illustrates the descriptive statistics for the demographic variables of the participants. As seen in the table, the typical participant was a middle aged male. For the majority of the sample, the ocular diagnosis refers to the main cause of visual impairment as reported by the participant since previous sight test records were not available for all participants. The most common reported primary causes were RP (40%), and glaucoma (42%). The majority of participants reported living with their partners (63%). Participants were mostly retired (50%), although a significant portion were working full time (31%). Approximately half of the sample were registered severely sight impaired (42%). A similar number reported using mobility aids (39%) and low vision aids (44%).

Gender (n)	31 male, 21 female
Age (years)	
Median (25% IQ-75% IQ)	61(49-68)
Min-max	31-96
Ocular diagnosis (n)	
RP	21
Glaucoma	22
Vascular occlusion	2
Retinal detachments/tears	2
Other	5
Duration of visual impairment (years)	
Median (25% IQ-75% IQ)	15(6-26)
Min-max	1-63
Registration status (n)	
Registered severely sight impaired	22
Registered sight impaired	6
Not registered	24
Living arrangements (n)	
Alone	14
With partner	33
With other	4
Warden assisted	1
Current employment status (n)	
Working full time	16
Working part time	6

Student	3
Unemployed	1
Retired	26
Number of prescribed medications (n)	
Median (25% IQ-75% IQ)	2(0.5-2.5)
Min-max	0-11
Number of co-morbidities (n)	
Median (25% IQ-75% IQ)	2(1-3)
Min-max	0-5
Use of mobility aids (n)	
White cane or guide dog	20
No mobility aids used	32
Use of low vision aids (n)	
Yes	23
No	29
Have you fallen in the past 12mos? (n)	
Yes	23
No	29
Spectacle type worn when walking around	
Single vision distance	21
Multifocals	13
No spectacles worn	18

Table 3.1 Descriptive statistics for the demographic variables.

3.3.2.1 Ordinal analysis of D-AI responses

The difficulty of goals was graded by the respondent on a five point scale (1- not difficult, 2- slightly difficult, 3- moderately difficult, 4- very difficult, and 5- impossible without help). Goals deemed by the respondent as irrelevant were recorded as not important/not applicable and were deemed missing values. The difficulties of these goals were not assessed and were omitted from the statistical analysis. Mean values were calculated for each domain and goal, and these were used for analysis, with higher values indicating greater perceived difficulty.

Descriptive statistics of the questionnaire scores are provided in Appendix 2. Mobility was the most difficult domain ($\bar{x}$=2.14 ±0.13) reflecting the results of a previous study that investigated the perceived visual difficulties of those with retinitis pigmentosa, and found worse reported function with activities relating to orientation and mobility (Latham et al., 2015a). This is supported by other similar studies (Szlyk et al., 1998; Noe et al., 2003) that found worse perceived mobility function in individuals with RP and glaucoma respectively. It has also been suggested that together with reading, outdoor mobility function is the main priority in individuals with visual field loss secondary to glaucoma (Aspinall et al., 2008). The two goals underlining this domain that were reported most difficult were self-reported mobility difficulty indoors in unfamiliar surroundings ($\bar{x}$=2.50 ±0.17) and mobility outdoors ($\bar{x}$=2.37 ±0.17).

The second most difficult domain was learning and applying knowledge ($\bar{x}$=2.10 ±0.15). Reading was the most difficult reported goal underpinning this domain ($\bar{x}$=2.17 ±0.16), reflecting the results of one study that found worse self-reported reading ability relative to other domains regardless of ocular diagnosis (Ahmadian & Massof, 2008). The least difficult domain was self-care ($\bar{x}$=1.19 ±0.05), and the least difficult reported goal overall underpinned this domain (being able to take care of your personal hygiene without assistance, $\bar{x}$=1.10 ±0.04). For half of the domains, the range of self-reported visual function was at least 3, indicating a wide range of ability levels in the sample in these domains. These included learning and applying knowledge, general tasks and demands, and mobility. The self-care domain had the least range in its mean scores (1.50).

Although skewness and kurtosis figures suggest a normal distribution (0.834 and -0.424 respectively), the Kolmogorov-Smirnov test indicates the summed responses to the D-AI questionnaire are not normally distributed (0.191, $p<0.001$).

3.3.2.2 Rasch analysis of D-AI responses

Rasch analysis of the data were undertaken as outlined in Chapter 2 with Winsteps (version 3.91.0; winsteps.com), using a single Andrich rating scale model (Andrich, 1978).

Person measures for overall self-reported function were derived from the data set directly, using all 44 goals assessed. Higher person measures indicate higher ability. Higher item difficulties indicate easier tasks (Table 3.2). Category functions were ordered (Andrich thresholds none, -0.86, -0.51, 0.51 and 0.86), each of which was the most probable response at some point on the scale. Person separation was 2.51 (reliability 0.86), and item separation was 3.06 (reliability 0.90), indicating that the instrument ranks both people and items acceptably. Targeting was +2.09±1.86 logits, poorer than the ideal and indicating that this sample has a higher ability, on average, than the instrument is aimed at.

Only 54% of variance is explained by the primary measure, slightly lower than the ideal. As expected due to wide ranging nature of the instrument, and as found in the original Rasch validation (Latham et al., 2015a), there are five significant contrasts, with the largest having a strength of 5.2 eigenunits. There are some misfitting items (Table 3.2), with six items with fits in the range 1.5-2.0 and a further two with fits greater than two (outfits of 2.18 and 2.36). The lack of exact fit might be due to lower subject numbers than in the previous analysis. In large part, the relatively poor fits can be considered acceptable and do not diminish the validity of the measures (Linacre M., personal communication, 2015).

Goal	Domain	Item difficulty	SE	Infit mnsq	Oufit mnsq	Applicability
Applying for a job	Major life areas	-1.31	0.23	1.18	0.97	24
Mending clothes	Domestic life	-1.10	0.23	1.23	1.53	26
Doing general maintenance tasks at home	Domestic life	-1.10	0.23	1.22	1.50	44
Mobility indoors	Mobility	-1.10	0.16	0.52	0.79	52
Doing laundry	Domestic life	-0.95	0.18	0.96	1.22	44
Mobility outdoors	Mobility	-0.92	0.16	1.02	1.43	52
Using public transport	Mobility	-0.79	0.16	0.54	0.45	52
Shopping	Domestic life	-0.79	0.16	0.85	0.69	52
Physical activity and / or sport	Community, social and civil life	-0.66	0.20	1.07	1.28	37
Reading	Learning and applying knowledge	-0.65	0.16	1.05	1.48	52
Social events	Community, social and civil life	-0.57	0.17	0.85	0.79	52
Writing	Learning and applying knowledge	-0.54	0.17	1.34	1.28	52
Personal administration	General tasks and demands	-0.54	0.17	0.99	0.76	52
Holidays and trips	Community, social and civil life	-0.53	0.17	0.61	0.49	50
(Grand) child care	Domestic life	-0.51	0.25	1.08	2.36	25
Grocery shopping	Domestic life	-0.51	0.17	0.66	0.54	50
Working activities	Major life areas	-0.47	0.20	0.95	0.78	39
Watching TV	Learning and applying knowledge	-0.43	0.17	0.82	0.73	52
Accessibility at work, such as moving around and using facilities	Major life areas	-0.43	0.20	0.86	0.64	38
Dining out	Community, social and civil life	-0.41	0.17	0.43	0.44	51
Participating in Education	Major life areas	-0.26	0.29	0.76	0.57	15

Interaction with strangers	Interpersonal interactions and relationships	-0.25	0.17	1.18	0.90	52
Health care for another adult	Domestic life	-0.19	0.46	0.87	0.52	13
Prepare your usual daily meals	Domestic life	-0.13	0.18	0.97	0.70	50
Interaction with colleagues	Interpersonal interactions and relationships	-0.11	0.21	1.29	1.04	38
Dealing with personal correspondence	Communication	0.10	0.19	1.42	1.46	52
Withdrawing money and paying	Domestic life	0.10	0.19	1.29	1.00	52
Using a computer	Communication	0.20	0.21	1.3	1.65	47
Getting information	Major life areas	0.25	0.19	1.74	1.3	52
Following a schedule and getting to appointments on time	General tasks and demands	0.33	0.20	1.43	1.11	52
Communicating with people face to face	Interpersonal interactions and relationships	0.33	0.20	1.24	0.99	52
Managing finances	Major life areas	0.33	0.20	1.71	1.32	52
Cleaning and tidying up	Domestic life	0.45	0.22	1.57	0.98	47
Pet care	Domestic life	0.46	0.33	1.01	0.72	18
Relationship with loved ones	Interpersonal interactions and relationships	0.58	0.22	1.23	0.87	52
Mobility at home	Mobility	0.68	0.22	0.76	0.60	52
Recreational / leisure time activities	Community, social and civil life	0.73	0.23	1.60	1.15	52
Having visitors	Community, social and civil life	0.78	0.23	0.54	0.48	52
Using a telephone	Communication	1.02	0.26	1.45	1.66	52
Eating and drinking	Self care	1.24	0.28	0.95	0.48	52
Personal health care and medication	Self care	1.40	0.3	0.92	0.49	52
Dressing	Self care	1.50	0.32	0.83	0.44	52

Following the news	Community, social and civil life	1.50	0.32	1.28	1.14	52
Personal hygiene	Self care	2.18	0.44	0.83	2.18	52

Table 3.2 Item parameters of the 44 goals of the Dutch ICF Activity Inventory as determined by Rasch analysis. Goals are ordered by item difficulty, with the most difficult item first. Infit and oufit mnsq values, indicating the fit of the item to the underlying unidimensional construct are given. Applicability indicates the number of participants (max n=52) to whom the item was important or applicable.

However, to investigate further whether misfitting items should be excluded from the analysis, the analysis was repeated with misfitting items removed. Initially, the two items with outfits greater than 2 were excluded. The analysis was re-run with these 2 items (personal hygiene n=52, (grand)child care n=25) excluded. All items then had fits in the range 0.5-2.0, but other parameters were similar (person separation 2.44, item separation 2.89, targeting 2.08±1.90, variance explained by the primary measure 53%, 5 contrasts greater than 2 eigenunits). Person measures with the 44 item instrument were not different from those with the 44 item instrument ($t(51)=0.54$, $p=0.60$) and this reduced scale is highly correlated with the original scale ($R^2=0.99$, $p<0.001$).

A further reanalysis iteratively removed items with greatest misfit until all items fell in the range 0.5-1.5. Twenty four items remained in the instrument after this process. The variance explained by the primary measure rose to 57% and the number of contrasts fell to three, with a maximum value of 3.2 eigenunits. However, reliability measures remained similar (person 2.09, item 3.13), and the number of participants achieving a 'maximum measure' (i.e. reporting ‘no difficulty’ to any item) rose from five in the 44 item instrument to 14 in the 24 item instrument. This reduced scale is highly correlated with (R^2=0.924, p<0.001) but significantly different from (paired t-test, t(52)-4.54, p<0.001) the 44 goal person measures.

In addition to the overall scale, person measures were also derived by Rasch analysis for the most difficult individual domain of the questionnaire identified in the ordinal analysis, i.e. ‘mobility’. For the mobility domain, which consists of four goals, person separation was 2.33 (reliability 0.84), and item separation was 6.14 (reliability 0.97), with all items fitting in the range 0.5-1.5 mean square. Similarly to the previous analyses, targeting is poor (+2.81±3.26 logits), but the mobility items do constitute a reasonable and unidimensional subscale and these person measures are considered to represent mobility function in the remainder of the results. The variance explained by the primary measure was 75%, and there were no significant contrasts. Person measures derived from this analysis were therefore used to represent self-reported mobility function.

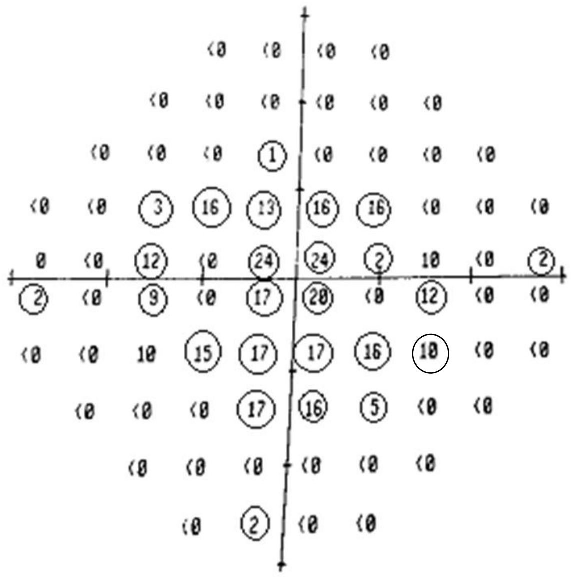
3.3.3 Other clinical variables

Table 3.3 provides descriptive statistics of the clinical visual function assessments (n=52). The results demonstrate a wide range of values observed in all parameters.

	Mean (±std)	Median (25% IQ-75% IQ))	Range
Binocular VA (LogMAR)	+0.34(±0.09)	+0.07(-0.07-0.46)	-0.22-3.00
Binocular CS (LogCS)	+1.44(±0.08)	+1.63(1.20-1.95)	0.00-1.95
Binocular reading acuity (LogMAR)	+0.50(±0.12)	+0.18(0.02-0.41)	-0.13-3.00
Maximum reading speed (words per minute (wpm))	141.17(±6.84)	150.10(122.15-171.37)	57.16-136.79
Critical print size (LogMAR)	0.45(±0.05)	0.40(0.20-0.60)	0.00-1.30

Table 3.3 Descriptive statistics of the clinical visual function assessments (n=52). The mean ± standard deviation, and the median (interquartile range) are given.

3.3.4 Derivation of static perimetric mean threshold



$$\text{Mean threshold} = \frac{\text{Sum of threshold values}}{\text{No of test points}}$$

1+3+16+13+16+16+12+24+24+2+2+2+9+17+20+12+15+17+17+16+17+16+5+2 / 76 = 4dB

Figure 3.1 Example visual field results demonstrating how the mean thresholds used in the analysis were derived for the central 30 degrees. The absolute values by the HFA 30-2 and 60-4 programs are used to manually calculate the mean threshold of the visual field areas.

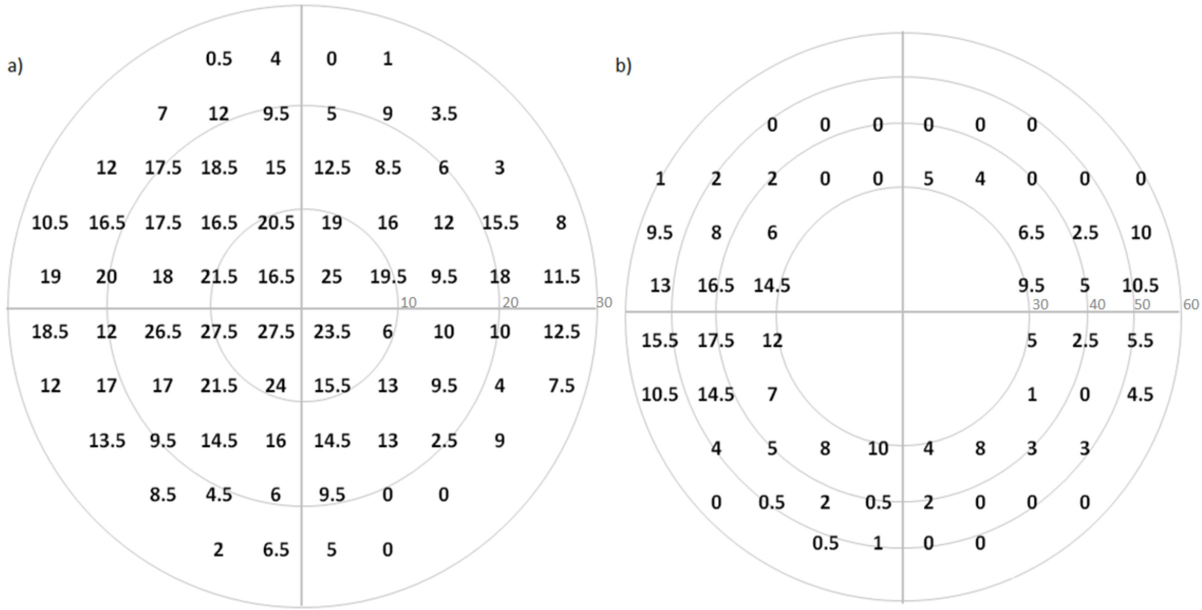


Figure 3.2 Threshold values representing the median of the mean threshold of the sample (n=52) at each test location for (a) central 30-2, and (b) peripheral 60-4 tests.

The derivation of the mean threshold for the visual field results is outlined in Figure 3.1, and the median of the mean threshold values of the sample for each location within the central 30-2 and peripheral 60-4 test programmes are demonstrated in Figure 3.2. The absolute values provided by the HFA 30-2 and 60-4 programs were used to manually calculate the mean threshold of central and the peripheral visual field (Figure 3.1).

Twelve percent of participants had difficulty either seeing the standard fixation target or maintaining single vision during the assessment. For these participants, the custom fixation target was used. Ninety eight per cent of false positive statistics ($\bar{x}$=2.74 ±0.91), and ninety four per cent of false negative statistics ($\bar{x}$=4.89 ±1.25) were less than an acceptable value of 20%. A cut-off value of 20& was used to determine acceptable reliability (Newkirk et al., 2006). Fixation accuracy, defined as combination of false positives and false negatives, was found to significantly associated (Bonferroni Corrected significance level of $p=0.004$ is used) with field loss severity ($R^2=0.20$, $p<0.001$). A correlation was also found between sight loss registration and fixation accuracy, with participants registered as severely sight impaired making greater fixation losses ($R^2=0.20$, $p<0.001$). Fixation accuracy was also found to relate to the overall D-AI person measure. Those who reported greater overall self-reported difficultly had poorer fixation accuracy ($R^2=0.32$, $p<0.001$). Although false negative statistics were not significantly associated with the degree of visual field loss ($R^2=0.00$, $p=0.896$), greater visual field loss was found to relate to a greater number of false positives ($R^2=0.39$, $p<0.001$). Further, weaker correlations were found between false positive statistics and the duration of visual impairment ($R^2=0.19$, $p<0.001$), and sight loss registration ($R^2=0.19$, $p<0.001$). Individuals who reported longstanding visual impairment and those not registered as sight impaired or severely sight impaired were found to make higher number of false positive responses.

A significant Kolmogorov-Smirnov statistic indicates a non-normal distribution of the overall visual field scores (0.147, $p=0.006$), although skewness and kurtosis figures may suggest a normal distribution (0.234 and -1.466 respectively).

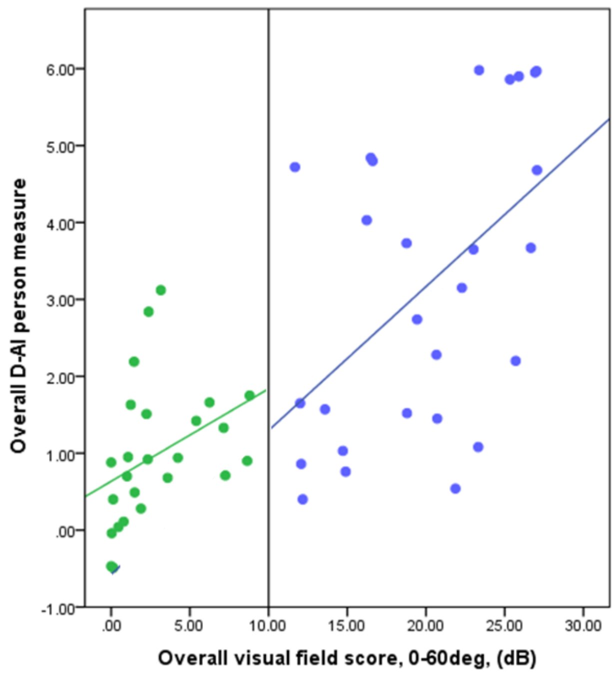


Figure 3.3 Graphical representation of the relationship between overall field score and overall D-AI score, and the dependency of this relationship on the overall field score. Green points represent scores <10dB, blue points represent scores >10dB. Regression lines represent the correlation between the overall field score and overall D-AI score separately for the better and worse field groups.

Statistical analysis was initially undertaken on the sample in its entirety (n=52). The sample was also split into two groups based on participants' overall visual fields scores for further analysis. Individuals with an overall visual field score of ≥10dB were defined as having 'better fields' (n=27), and participants with an overall field score of <10dB were defined are having 'worse fields' (n=25). Descriptive statistics of the visual scores in these groups are provided in Table 3.4. The cut-off point chosen to define these groups is close to the overall visual field median of the entire sample (12.95dB). Figure 3.3 shows a vertical cluster of points near the y-axis representing individuals with an overall visual field score of < 10dB. Despite all having a similar degree of poor visual fields, there is a wide variation in the D-AI person measures of these participants. This suggests that in individuals with an overall field score of <10dB, the visual field may be a poor indicator of self-reported visual function, and exploration of whether self-reported difficulty might be limited by different factors depending on the level of visual field loss was warranted. The cut-off point chosen to define better and worse visual field scores in our data (10dB) is the same as the stimulus luminance adopted by the Esterman visual field test (Esterman, 1982), and the standard target luminance used in Goldmann kinetic perimetry (Goldmann III-4e stimulus). It is also the target luminance recommended in the AMA "Guides to Impairment" (Rondinelli et al., 2009) that is used to evaluate the visual field to define legal blindness (Langelaan et al., 2006).

a) Entire sample	Mean	Median (25% IQ-75% IQ))	Range
Central visual field (0-30 deg)	14.08(±1.57)	12.95(3.05-24.09)	0.00-31.75
Peripheral visual field (30-60 deg)	8.68(±1.12)	7.53(0.01-15.47)	0.00-22.98
Overall visual field (0-60 deg)	11.70(±1.36)	11.84(2.07-20.69)	0.00-27.05
b) Better fields	**Mean**	**Median (25% IQ-75% IQ))**	**Range**
Central visual field (0-30 deg)	23.69(±1.11)	23.75(20.72-28.66)	11.14-31.75
Peripheral visual field (30-60 deg)	15.10(±1.05)	15.27(10.62-20.13)	3.80-22.98
Overall visual field (0-60 deg)	19.90(±1.01)	20.66(14.90-25.33)	11.68-27.05
c) Worse fields	**Mean**	**Median (25% IQ-75% IQ))**	**Range**
Central visual field (0-30 deg)	8.71(±0.71)	2.84(1.05-5.16)	0.00-12.68
Peripheral visual field (30-60 deg)	1.75(±0.62)	0.00(0.00-2.81)	0.00-12.08
Overall visual field (0-60 deg)	2.85(±0.57)	1.89(0.63-4.82)	0.00-8.47

Table 3.4 Descriptive statistics of the visual field scores for (a) the entire sample, (b) better field scores (≥10dB) and c) worse fields scores (<10dB). Higher scores indicate greater mean thresholds, and better visual fields.

3.3.5 Relationship between self-reported function and the predictor variables

3.3.5.1 Demographic variables

Demographic variables were compared to self-reported function. Due to the multiple number of comparisons performed (12) a more stringent significance level is more appropriate for these tests, as suggested by the Bonferroni correction (Field, 2005). A corrected significance level of p<0.004 was used. The complete correlations are listed in Table 3.5, and significant correlations are shown in Figure 3.4.

Mann-Whitney U tests were conducted for the dichotomous predictors in Table 3.1 to establish whether the means of the independent samples significantly differed (Table 3.5). Self-reported mobility related function was significantly more difficult for individuals who reported using mobility aids ($\bar{x}$=0.38, SD=2.10) than for those who did not ($\bar{x}$=4.32, SD=2.99) (Mann-Whitney U=101.50, p<0.001). Similarly, comparing the difference in overall self-reported function between individuals who used low vision aids ($\bar{x}$=0.90, SD=0.68), and those who did not ($\bar{x}$=2.97, SD=2.00) indicated a significant difference between the groups (U=107.50, p<0.001). However, since the effect sizes are small (Cohen's d = 0.13 and 0.012 respectively), these differences are inconsequential despite their statistical significance.

Kruskal-Wallis tests were performed on the categorical variables in Table 3.1 as a non-parametric determination of differences between the independent groups. None of the variables were significantly related to overall and mobility related self-reported function.

The ordinal and continuous demographic variables in Table 3.1 were compared to D-AI scores in 2-tailed Spearman's rho bivariate correlations. As Table 3.5 and indicates, the strongest relationship between self-reported visual function and a demographic variable was that sight loss registration significantly predicted overall self-reported function (R^2=0.50, p<0.001), where participants registered as severely sight impaired reported worse function. A further weaker relationship was found between overall self-reported function and the duration of visual impairment in Table 3.5 as χ^2 (R^2=0.16, p=0.004), with participants with longstanding visual impairments reporting greater overall difficulty. Bivariate correlations were also performed to compare the demographic variables to self-reported difficulty in mobility related goals (Table 3.5). Self-reported mobility difficulty was found to be most significantly related with sight test registration (R^2=0.45, p<0.001), where participants registered as severely sight impaired reported worse function. The duration of visual impairment (R^2=0.23, p<0.001) was also found to be a significant predictor of self-reported mobility function. Participants who reported longstanding visual impairment reported greater perceived mobility difficulty.

Demographic variables	**Overall D-AI score**	**Mobility function**
Dichotomous variables (U)		
Gender	U=286.00	U=275.00
Use of mobility aids	U=112.50*	U=101.50*
Use of low vision aids	U=107.50*	U=166.50
Have you fallen in the past 12 months?	U=208.50	U=225.00
Nominal variables (χ^2)		
Ocular diagnosis	χ^2=13.57	χ^2=15.35
Living arrangements	χ^2=0.98	χ^2=1.79
Current employment status	χ^2=2.71	χ^2=2.00
Continuous variables (R^2)		
Sight loss registration	R^2=0.51*	R^2=0.46*
Age	R^2=0.03	R^2=0.05
Duration of visual impairment	R^2=0.16	R^2=0.23*
Number of medications	R^2=0.00	R^2=0.01
Number of comorbidities	R^2=0.12	R^2=0.07

Table 3.5 Relationship between overall D-AI and self-reported mobility function and the demographic variables (*p<0.004, all others p≥0.004).

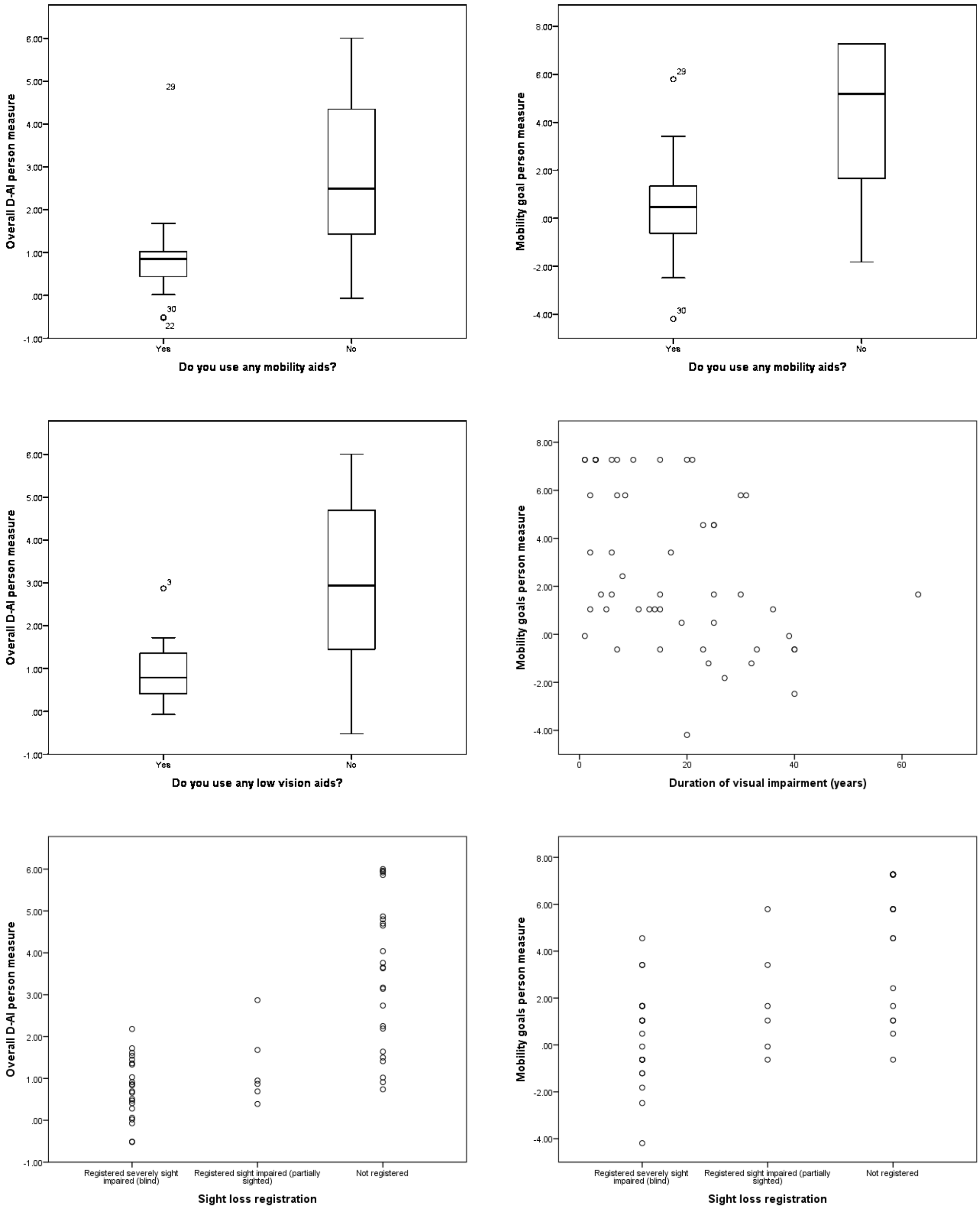


Figure 3.4 Box plot graphical representations of the significant relationship between demographic variables and self-reported function.

3.3.5.2 RP vs glaucoma

Descriptive statistics of the visual field scores for participants with the most commonly reported primary diagnoses are provided in Table 3.6.

a) RP, n=21	**Mean**	**Median (25% IQ-75% IQ))**	**Range**
Central visual field (0-30 deg)	4.07(±1.14)	2.67(1.05-4.75)	0.00-23.34
Peripheral visual field (30-60 deg)	1.92(±0.82)	0.00(0.00-2.74)	0.00-12.35
Overall visual field (0-60 deg)	3.12(±0.85)	1.49(0.63-3.92)	0.00-14.72
b) Glaucoma, n=22	**Mean**	**Median (25% IQ-75% IQ))**	**Range**
Central visual field (0-30 deg)	20.60(±1.97)	23.51(13.80-27.82)	0.00-30.28
Peripheral visual field (30-60 deg)	13.33(±1.52)	14.39(9.73-18.73)	0.00-22.98
Overall visual field (0-60 deg)	17.39(±1.74)	19.11(12.01-23.38)	0.00-27.02

Table 3.6 Descriptive statistics of the visual field scores for (a) participants with RP, (b) participants with glaucoma and Higher scores indicate greater mean thresholds, and better visual fields.

	Ocular diagnosis			
	RP	**Glaucoma**	**Other**	**Total**
Better visual fields (>10dB)	2	17	8	27
Worse visual fields (<10dB)	19	5	1	25
Total	21	22	9	52

Table 3.7 A cross table displaying the distribution of primary ocular diagnoses in each of the visual field groups.

Kruskal-Wallis tests were also performed to determine if significant differences exist between participants with the two principal causes of visual impairment: 83% of participants reported either glaucoma or retinitis pigmentosa as their primary cause of visual impairment (Table 3.1). There are significant differences in overall self-reported function (chi-square=11.08, $p<0.001$) and mobility related function (chi-square=12.65, $p<0.001$) depending on ocular diagnosis, with participants with glaucoma reported less overall and mobility related self-reported difficulty compared with those with RP (Figure 3.5). However there are large differences in the degree of visual field loss between participants depending on their ocular diagnosis as demonstrated in Table 3.6. 91% of participants with RP had an overall visual field score of <10dB, whereas only 23% of those with glaucoma were defined as having "worse fields". This suggests that the differences between the RP and glaucoma groups are likely primarily due to the degree of residual visual field, as opposed to the ocular diagnosis. Differential item functioning (DIF) by ocular diagnosis was also considered for the D-AI results to determine whether any item was answered differently depending on the ocular condition of the participant. DIF was considered as significant if the difference in item difficulty between groups (DIF contrast) was greater than 0.5 logits, and was significant at the 1% level (Latham et al., 2015a). No item showed significant DIF by ocular diagnosis, indicating that the questions were responded to in a similar way by those with RP and with glaucoma.

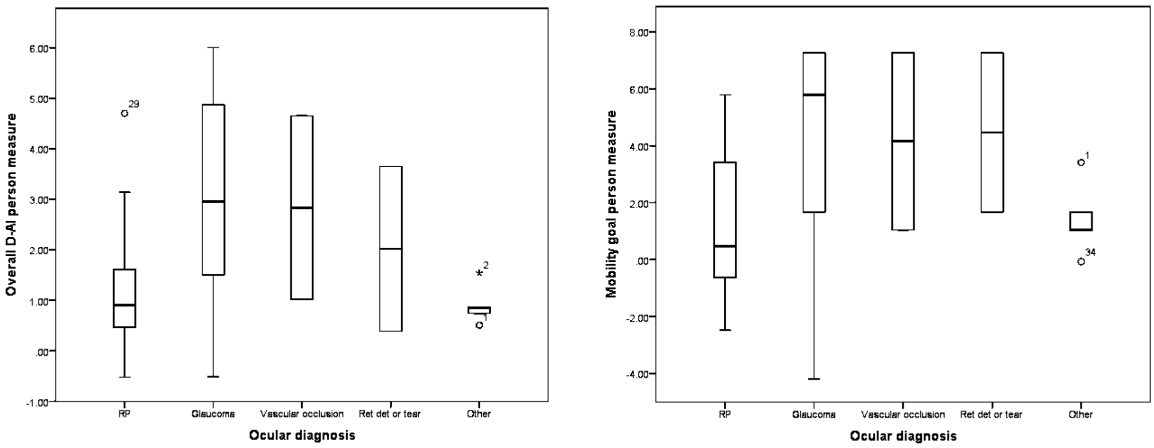


Figure 3.5 Box plot graphical representations of the association between ocular diagnosis and self-reported function (RP n=21, glaucoma n=22, vascular occlusion n=2, retinal detachment or tear n=2, other n=5).

3.3.5.3 Other clinical functions

Clinical measures of visual function were compared to self-reported function in bivariate analyses. Due to the multiple number of comparisons performed (9) a more stringent significance level is more appropriate for these tests, as suggested by the Bonferroni correction (Field, 2005). A corrected significance level of $p<0.01$ was used.

	Overall D-AI score (R^2)	Mobility function (R^2)
Binocular VA (LogMAR)	0.52*	0.40*
Binocular CS (LogCS)	0.52*	0.38*
Binocular reading acuity (LogMAR)	0.54*	0.42*
Critical print size (LogMAR)	0.38*	0.22*
Maximum reading speed (wpm)	0.20*	0.06

Table 3.8 Bivariate analysis between overall D-AI and self-reported mobility function and the clinical visual function variables. Non parametric 2-tailed Spearman's correlations coefficients are used (*$p<0.002$, all other others $p\geq0.002$).

Table 3.8 and Figure 3.6 illustrate the results of bivariate analyses for clinical visual function. All clinical visual function variables correlate significantly ($p<0.002$) with overall self-reported visual function, with the most significant relationship found between overall self-reported function and binocular VA ($R^2=0.52$, $p<0.001$) and binocular CS ($R^2=0.52$, $p<0.001$). Perceived mobility function correlated similarly with binocular VA ($R^2=0.40$, $p<0.001$) and binocular CS ($R^2=0.38$, $p<0.001$). The relationship with critical print size and maximum reading speed were weaker and therefore not shown in Figure 3.6.

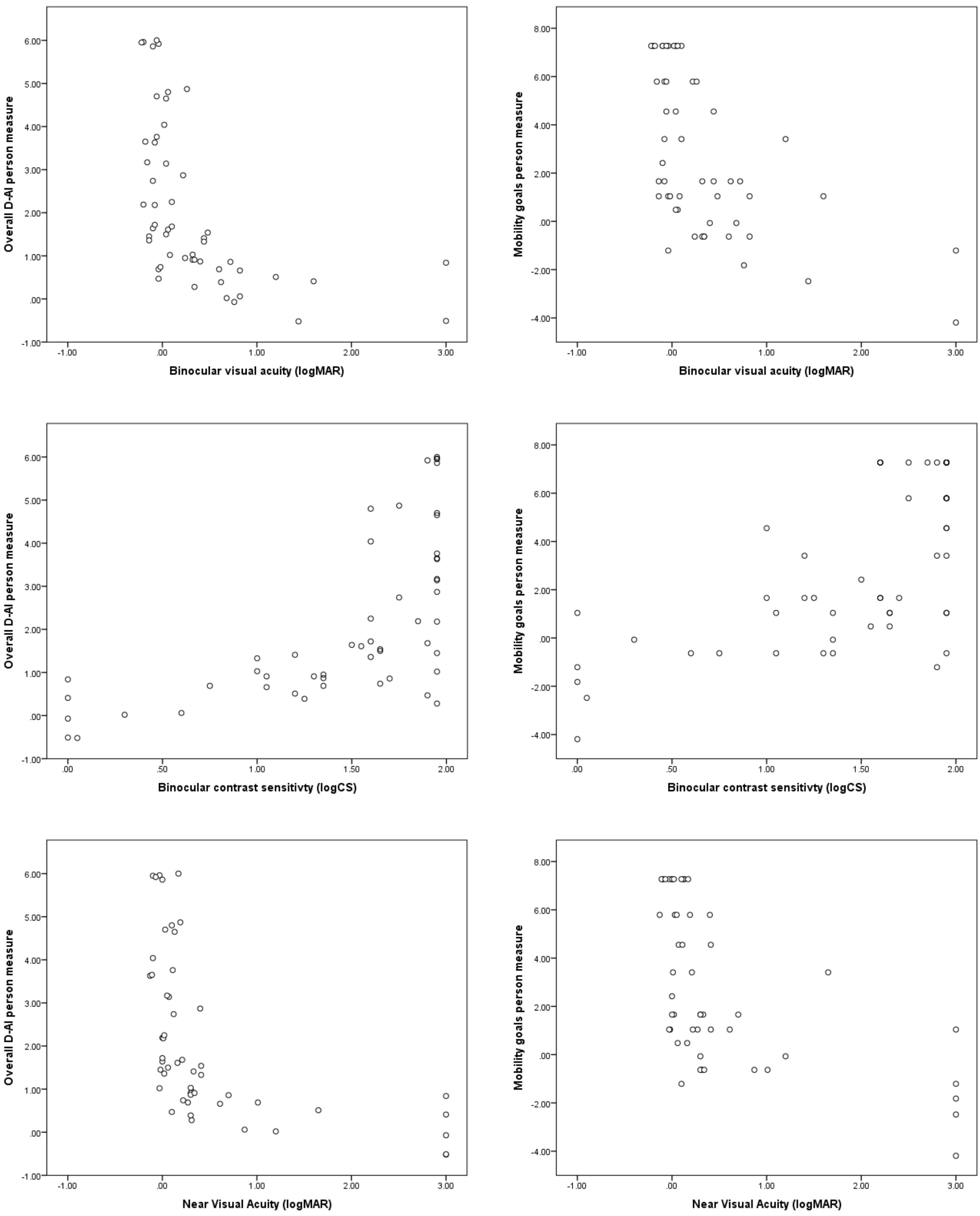


Figure 3.6 Plots of the clinical function assessment variables correlated with overall self-reported function mobility function.

3.3.5.4 Visual field

The overall (0-60 deg) visual field for all participants was divided into central (0-30 deg) and peripheral areas (30-60 deg). The mean thresholds of these two bands were calculated and used for analysis. Mean thresholds were also calculated for finer annular divisions of the visual field, but were rejected since they supported but failed to supplement findings from the two band analysis.

	Overall D-AI score	**Mobility function**
Overall field (0-60 deg)	0.50*	0.64*
Central field (0-30 deg)	0.49*	0.61*
Peripheral field (30-60 deg)	0.48*	0.63*

Table 3.9 Bivariate analysis between the overall, central and peripheral visual field results, and self-reported visual function overall, and mobility function. Non parametric 2-tailed Spearman's correlations coefficients are used (*p<0.001).

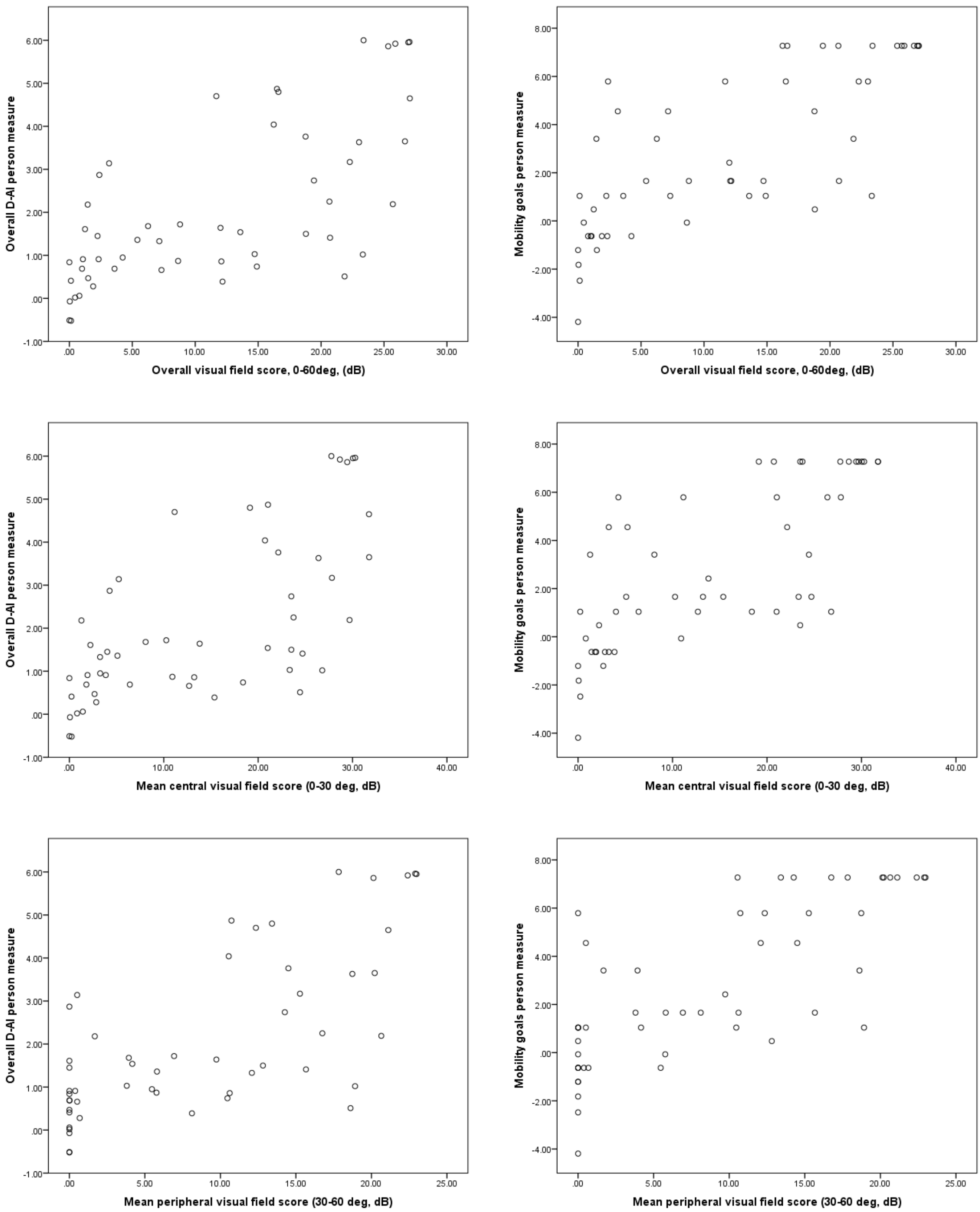


Figure 3.7 Plots of the visual field assessment variables correlated with overeall self-reported function mobility function

Greater visual field loss (0-60 deg) is associated with greater self-reported difficulty (R^2=0.50, $p<0.001$). The overall binocular visual field is in particular a good predictor of self-reported difficulties in mobility related activities (R^2=0.64, $p<0.001$) (Table 3.9 and Figure 3.7).

The relationship between the overall visual field and self-reported difficulty does not appear to be greatly dependent on eccentricity. The peripheral and central visual field are similarly correlated with self-reported function. This was found when relating the visual field with overall perceived function (R^2=0.49, $p<0.001$ central and R^2=0.48, $p<0.001$ peripheral) and mobility related function (R^2=0.61, $p<0.001$ central and 0.63, $p<0.001$ peripheral).

3.3.6 Multiple regression analysis

Clinical function variables that were identified as significantly associated with perceived overall and mobility function: central (0-30 deg) and peripheral (30-60) visual field mean thresholds, binocular VA (as a global measure of acuity), and binocular CS were entered into stepwise multiple regressions to determine which independently explained significant amounts of variance in overall and mobility self-reported function (Table 3.10). The peripheral (30-60 deg) visual field was found to account for most variance (50%) in overall self-reported function. Also significant in this model was binocular CS, which explained a further 9% of variance. For self-reported mobility function, the peripheral (30-60 deg) visual field explained 59% of the variance in self-reported mobility function. When combined with binocular CS this increased to 67%.

	B	SE B	β	R^2 change	95% confidence interval	
Overall D-AI score					**Lower bound**	**Upper bound**
Constant	-0.53	0.44			-1.42	0.36
Peripheral (30-60 deg) field	0.12	0.03	0.51***	0.50***	0.07	0.17
Binocular CS	1.11	0.33	0.36**	0.09**	0.44	1.78
R^2	0.59					
Mobility function						
Constant	-1.90	0.70			-3.28	-0.51
Peripheral (30-60 deg) field	0.24	0.04	0.58***	0.59***	0.16	0.32
Binocular CS	1.83	0.53	0.34**	0.08**	0.78	2.89
R^2	0.67					

Table 3.10 Results of stepwise regression analyses to determine which of the identified significant clinical visual function variables best represents overall self-reported function, and mobility function using the entire sample (n=52). (B= unstandardised regression coefficients, SE B= standard errors, β= standardised regression coefficients R^2 change= amount of additional variance by including predictors from sample, Adjusted R^2= variance accounted for if derived from the population from which the sample was taken (Field, 2005) (* $p< 0.05$, **$p<0.01$, ***$p<0.001$).

The unstandardised regression coefficients of each model can be used to construct linear equations to predict overall self-reported function, and mobility function:

Overall self-reported function (logits) = -0.53 + (0.12 x peripheral visual field (dB)) + (1.11 x binocular CS (LogCS)

Mobility function (logits) = 1.90 + (0.24 x peripheral visual field (dB)) + (1.83 x binocular CS (LogCS))

Self-reported function can be estimated by inserting a single predictor variable value into these equations, provided that all other predictor variables remain constant. For example, from the unstandardised regression coefficients in Table 3.10, and the equations above, it can be predicted that as the peripheral visual field score worsens by 1dB, mobility is reported more difficult by 0.24 logits (±0.04), provided binocular CS remains constant. Graphical representations of these relationships are provided in Figure 3.8.

Standardised regression coefficients (β), as shown in Table 3.10 are not dependent on the units of measurement of the predictor variables because they are measured in standard deviation units. This enables the direct comparison of the relative influence of each predictor. Graphical representation of the relative influence of each significant predictor plotted against overall self-reported visual function, and self-reported mobility function is provided in Figure 3.9.

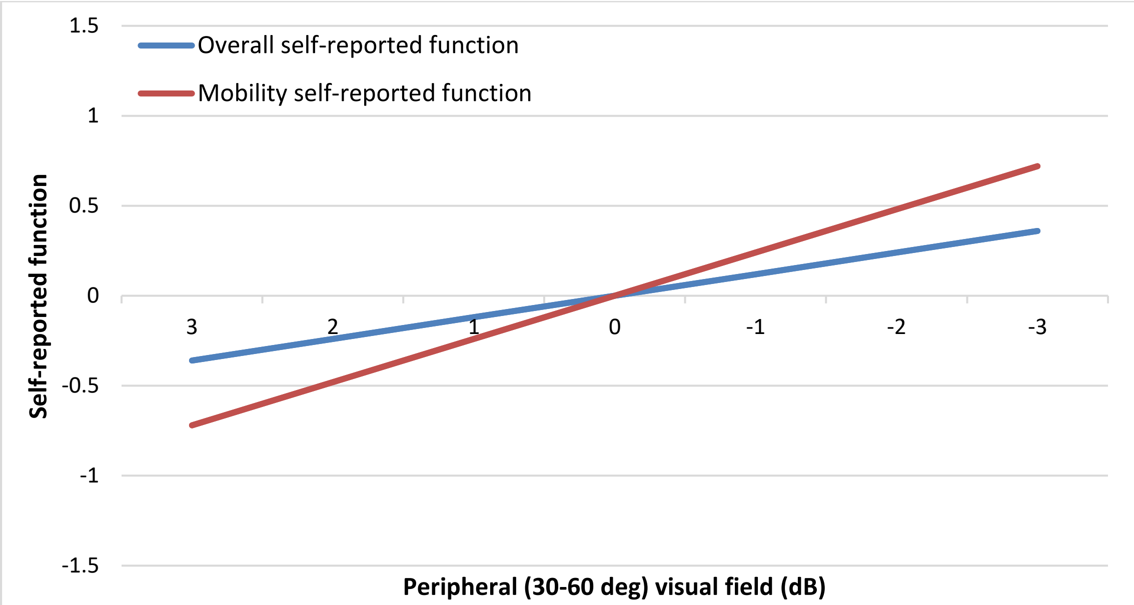
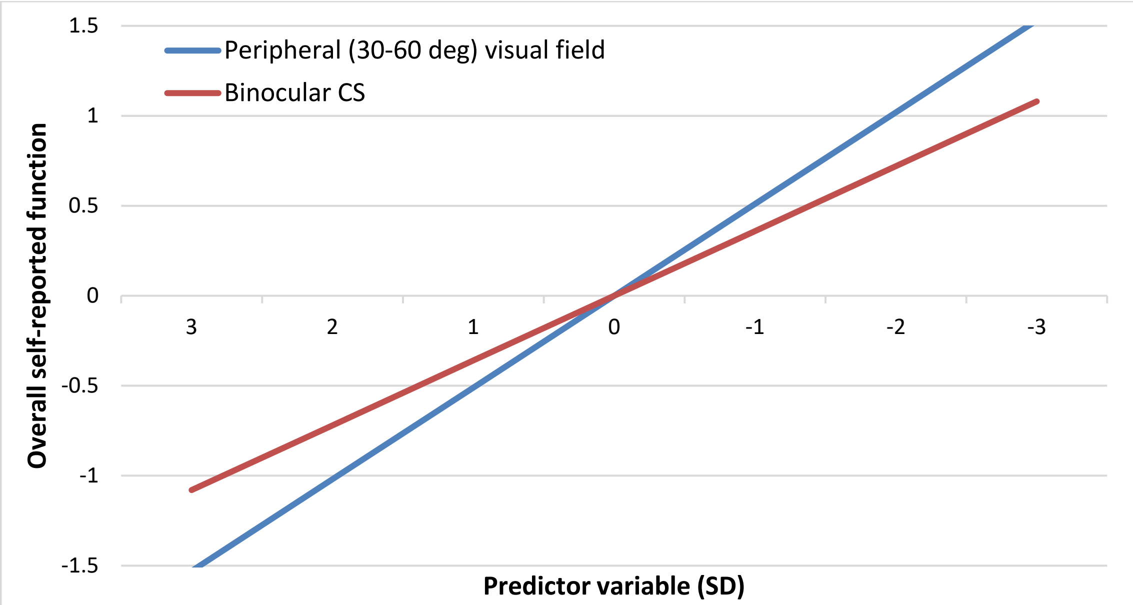
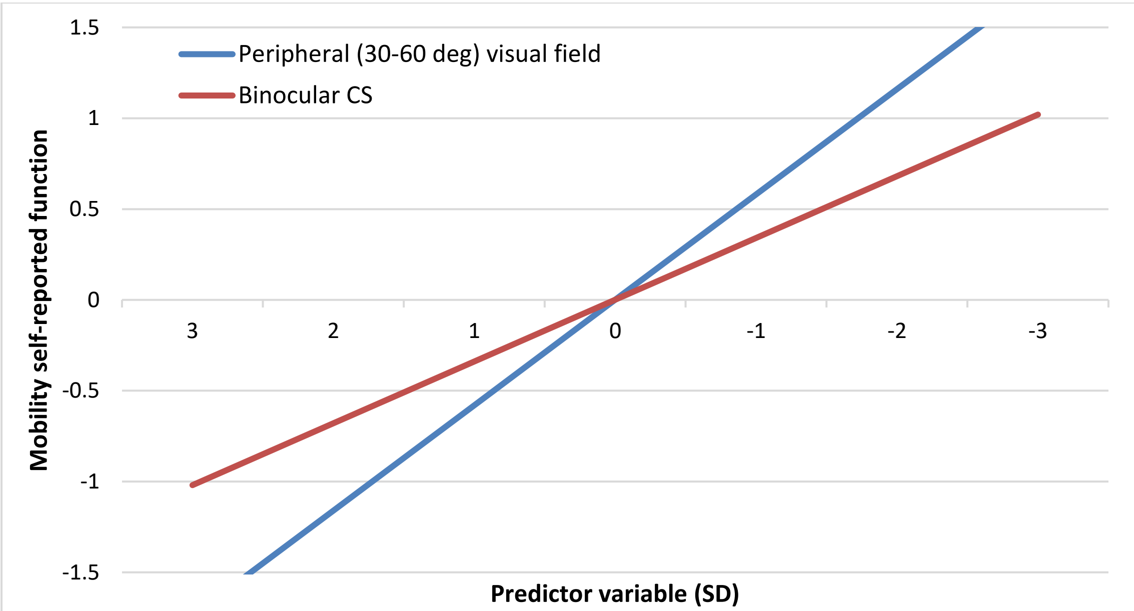


Figure 3.8 Graphical representations of the linear association of overall self-reported function, and self-reported mobility function against the predictor variable, the peripheral visual field. The effects of all other predictors must be constant for this graph to apply. A steeper slope indicates a stronger influence of the predictor variable on that area of self-report.



a)



b)

Figure 3.9 Graphical representations of the linear association of predictor variables against self-reported function (a) overall, and (b) mobility. The gradient of the line indicates the change in the self-reported function that would be associated with a specified change in the predictor variable. A steeper slope therefore indicates a stronger association between the predictor variable and outcome measure. The effects of all other predictors must be constant for these graphs to apply.

From the results given in Table 3.10, and depicted in Figure 3.9, the peripheral (30-60 deg) visual field most strongly influences overall and mobility related self-reported function. A loss of one standard deviation of the average mean threshold of the peripheral visual field results in worse self-reported visual function of between 0.51 and 0.58 standard deviations. Binocular CS was also found to significantly influence both overall and mobility self-reported function, with a loss of one standard deviation of binocular LogCS resulting in poorer self-reported visual function of between 0.34 and 0.36.

	Peripheral (30-60 deg) visual field	**Binocular CS**
Overall D-AI score	50%	9%
Mobility function	59%	8%

Table 3.11 Proportions of variance of self-reported visual function explained by demographic and clinical factors for overall, and mobility self-reported function.

The amounts of variance in self-reported visual function explained by the peripheral (30-60 deg) visual field is consistently and markedly greater than other predictors, and regardless of the dependant variable (Table 3.11).

3.3.6.1 Better vs worse visual fields

To investigate the difference between the clinical function indicators of self-reported function in participants with different degrees of visual field loss, additional multiple regression analyses were conducted. Binocular VA (as a global measure of acuity) and binocular CS were entered into a multiple regression with the mean threshold of the central (0-30 deg), and peripheral (30-60 deg) visual field using only participants with overall visual field scores of ≥ 10dB (n=27), and self-reported overall and mobility function as the dependant variables (Table 3.12).

	B	SE B	β	R^2 change	95% confidence interval	
Overall function					**Lower bound**	**Upper bound**
Constant	-4.71	1.83			-8.47	-0.95
Binocular CS	4.58	1.05	0.66***	0.43***	2.41	6.74
R^2	0.43					
Adjusted R^2	0.41					
Mobility function						
Constant	0.29	1.24			-1.06	4.27
Peripheral (0-60 deg) inferior field	0.30	0.08	0.62**	0.38**	0.01	0.40
R^2	0.38					
Adjusted R^2	0.35					

Table 3.12 Results of stepwise regression analyses to determine which clinical visual function variables best represent self-reported mobility function at goal level using only participants with overall visual field scores of ≥10dB. (B= unstandardised regression coefficients, SE B= standard errors, β= standardised regression coefficients R^2 change= amount of additional variance by including predictors from sample, Adjusted R^2= variance accounted for if derived from the population from which the sample was taken (Fields, 2005) (* p< 0.05, **p<0.01, ***p<0.001).

Binocular CS was selected as the only predictor of overall self-reported function in participants with overall visual field scores of greater than 10dB, accounting for 43% of the variance in results. The peripheral visual field was selected as the only predictor of perceived mobility function, explaining 38% of variance in results (Table 3.12).

	B	**SE B**	**β**	**R^2 change**	**95% confidence interval**	
Overall function					**Lower bound**	**Upper bound**
Constant	-0.08	0.25			-5.83	0.43
Binocular CS	0.91	0.18	0.72***	0.52***	0.54	1.29
R^2	0.52					
Adjusted R^2	0.50					
Mobility function					-3.09	-0.11
Constant	-1.60	0.72			0.82	3.04
Binocular CS	1.93	0.54	0.60**	0.36**	0.61	1.10
R^2	0.36					
Adjusted R^2	0.33					

Table 3.13 Results of stepwise regression analyses to determine clinical visual function variables best represent self-reported mobility function using only participants with overall visual field scores of <10dB. (B= unstandardised regression coefficients, SE B= standard errors, β= standardised regression coefficients R^2 change= amount of additional variance by including predictors from sample, Adjusted R^2= variance accounted for if derived from the population from which the sample was taken (Fields, 2005) (* $p< 0.05$, ** $p<0.01$, *** $p<0.001$).

When the multiple regression was repeated with participants with overall visual field scores of less than 10dB and entering the same predictor variables (binocular VA, binocular CS, mean threshold of the central (0-30 deg), and peripheral (30-60 deg) visual field), binocular CS was selected as the only predictor of overall self-reported function, and mobility function, explaining 52% and 36% of variance in results respectively (Table 3.13).

3.3.7 Further analysis of static retinal mean threshold: superior vs inferior visual field

To examine the difference between the superior and inferior visual field indicated in previous literature as outlined in Chapter 1, these visual field areas were compared to self-reported function in bivariate analyses. A Bonferroni corrected significance level of $p=0.008$ was used. Both the overall (0-60 deg) superior and inferior visual fields were found to be similarly correlated, but with a tendency for a slightly better relationship between inferior fields (Table 3.14) and overall D-AI scores ($R^2=0.41$, $p<0.001$ superior, $R^2=0.55$, $p<0.001$ inferior), and with mobility function ($R^2=0.56$, $p<0.001$ superior, $R^2=0.67$, $p<0.001$ inferior).

	Overall D-AI score	**Mobility function**
Overall (0-60 deg) superior	0.41*	0.56*
Overall (0-60) inferior	0.55*	0.67*
Central (0-30 deg) superior	0.38*	0.51*
Central (0-30 deg) inferior	0.53*	0.63*
Peripheral (30-60 deg) superior	0.34*	0.51*
Peripheral (30-60 deg) inferior	0.54*	0.64*

Table 3.14 Bivariate analysis comparing the superior and inferior visual field results with self-reported visual function overall and mobility. Non parametric 2-tailed Spearman's correlations coefficients are used. (*p<0.001)

A multiple regression analysis was conducted to investigate which clinical function variables, including the total superior and inferior (0-60 deg) visual field, independently explained significant amounts of variance in overall and mobility self-reported function. Binocular VA, binocular CS, and the total superior and inferior visual field scores were entered into the multiple regression. The inferior visual field explained 54% of overall self-reported function, and 61% when combined with binocular CS. The inferior visual field was also found to account for most variance (61%) in self-reported mobility function. Binocular CS explained a further 7% of variance (Table 3.15).

	B	**SE B**	**β**	**R^2 change**	**95% confidence interval**	
Overall function					**Lower bound**	**Upper bound**
Constant	-0.55	0.43			-1.42	0.36
Inferior visual field	0.10	0.02	0.56***	0.54***	0.07	0.17
Binocular CS	0.99	0.33	0.32**	0.07**	0.44	1.78
R^2	0.61					
Adjusted R^2	0.60					
Mobility function						
Constant	-1.96	0.68			-3.28	-0.51
Inferior visual field	0.19	0.03	0.61***	0.61***	0.16	0.32
Binocular CS	1.68	0.53	0.31**	0.07**	0.78	2.88
R^2	0.68					

Table 3.15. Results of stepwise regression analyses to determine which clinical function variables best represent overall self-reported function, and mobility function (n=52). B= unstandardised regression coefficients, SE B= standard errors, β= standardised regression coefficients, R^2 change= amount of additional variance by including predictors from sample, adjusted R^2= variance accounted for if derived from the population from which the sample was taken (Fields, 2005) (* $p< 0.05$, ** $p<0.01$, *** $p<0.001$).

3.3.7.1 Better vs worse visual fields

The importance of the inferior fields to self-reported visual function, in particular to self-reported mobility function is indicated more clearly when removing the poorer field scores (<10dB) from the bivariate regression analysis, as per the previous analysis (Table 3.16). In individuals with an overall (0-60 deg) visual field score of ≥10dB, the total (0-60 deg) inferior field is better related to overall self-reported visual function than the superior visual field (R^2=0.08, p=0.150, superior, R^2=0.34, p<0.001 inferior). The same was found with mobility related goals (R^2 =0.19, p=0.025, superior, R^2=0.45, p<0.001 inferior), suggesting that the total (0-60 deg) inferior visual field is a better predictor of self-reported mobility function than the total superior field in those with better overall fields..

When relating the superior and inferior central (0-30 deg) and peripheral (30-60 deg) visual field to mobility function, the same is found in participants with better (≥ 10dB) overall fields. The central (0-30 deg) inferior is better correlated with mobility function than the central superior field (R^2 =0.13, p=0.070, superior, R^2=0.40, p<0.001 inferior). The same was found when relating the peripheral (30-60 deg) inferior and superior visual field to mobility function (R^2 =0.16, p=0.036, superior, R^2=0.41, p<0.001 inferior).

The superior visual field was consistently found to lose its significance to the Bonferroni corrected 0.8% level when correlated with overall D-AI score, and mobility function in this group as Table 3.6 demonstrates, indicating the superiority of the inferior visual field over the superior visual field in predicting self-reported mobility function. Both the central and peripheral inferior visual fields was similarly related to mobility function (R^2=0.40, p<0.001 and R^2=0.41, p<0.001 respectively).

	Overall D-AI score	Mobility function
Overall (0-60 deg) superior	0.08	0.19
Overall (0-60) inferior	0.34*	0.45*
Central (0-30 deg) superior	0.07	0.13
Central (0-30 deg) inferior	0.34*	0.40*
Peripheral (30-60 deg) superior	0.06	0.16
Peripheral (30-60 deg) inferior	0.38*	0.41*

Table 3.16 Bivariate analysis, using only participants with overall visual field results ≥ 10dB, between superior and inferior visual field results and self-reported visual function overall and mobility. Non parametric 2-tailed Spearman's correlations coefficients are used (*$p<0.008$, for all others $p \geq 0.008$).

A multiple regression analysis was conducted to determine the significant variance in self-reported mobility function explained by the superior and inferior visual field. Binocular VA, binocular CS and mean threshold of the total (0-60 deg) superior, and inferior visual field were entered into a multiple regression using only participants with overall visual field scores of ≥ 10dB (n=27), and with self-reported mobility function as the dependant variable. The inferior visual field was found to account for 44% of the variance in self-reported mobility function. This supports the results of the previous bivariate analysis which suggests in individuals with better overall fields, the inferior visual field is the best predictor for self-reported mobility function (Table 3.17).

	B	SE B	β	R^2 change	95% confidence interval	
Mobility function					**Lower bound**	**Lower bound**
Constant	-0.94	1.36			-3.73	1.85
Overall (0-60 deg) inferior field	0.28	0.06	0.67***	0.44***	0.15	0.41
R^2	0.44					
Adjusted R^2	0.42					

Table 3.17 Results of stepwise regression analyses to determine clinical visual function variables best represent self-reported mobility function at goal using only participants with overall visual field scores of ≥10dB. (B= unstandardised regression coefficients, SE B= standard errors, β= standardised regression coefficients R^2 change= amount of additional variance by including predictors from sample, Adjusted R^2= variance accounted for if derived from the population from which the sample was taken (Fields, 2005) (* $p< 0.05$, **$p<0.01$, ***$p<0.001$).

For participants with worse overall fields (<10dB), both the superior and inferior visual field were similarly related to self-reported mobility function; unlike in participants with better overall fields (≥10dB), the inferior visual field was not a more significant indictor of mobility function (Table 3.18). The peripheral superior and inferior visual field lose their significance to the 0.8% Bonferroni corrected level when correlated with mobility function, most probably due to the limited degree of visual field remaining in this area.

	Overall D-AI score	Mobility function
Overall (0-60 deg) superior	0.35*	0.43*
Overall (0-60) inferior	0.31*	0.42*
Central (0-30 deg) superior	0.34*	0.38*
Central (0-30 deg) inferior	0.23	0.31*
Peripheral (30-60 deg) superior	0.19	0.21
Peripheral (30-60 deg) inferior	0.26	0.27

Table 3.18 Bivariate analysis, using only participants with overall visual field results <10dB, between superior and inferior visual field results and self-reported visual function overall and mobility. Non parametric 2-tailed Spearman's correlations coefficients are used (*$p<0.008$, for all others $p\geq0.008$).

When a second multiple regression analysis was conducted to determine the significant variance in self-reported mobility function explained by the superior and inferior visual field, using the same predictors, but using only overall field scores of <10dB, binocular CS was found to account for 36% of the variance in self-reported mobility function and the visual field was not selected (Table 3.19). This analysis suggests that while the inferior visual field is a significant predictor of self-reported mobility function in individuals with early and moderate visual field loss, self-reported mobility function is better indicated by other factors when visual field loss is more severe.

	B	SE B	β	R^2 change	95% confidence interval	
Mobility function					**Lower bound**	**Upper bound**
Constant	-1.60	0.72			-3.09	-0.11
Binocular CS	1.96	0.54	0.60**	0.36**	0.82	3.04
R^2	0.36					
Adjusted R^2	0.33					

Table 3.19 Results of stepwise regression analyses to determine clinical visual function variables best represent self-reported mobility function using only participants with overall visual field scores of <10dB. (B= unstandardised regression coefficients, SE B= standard errors, β= standardised regression coefficients R^2 change= amount of additional variance by including predictors from sample, Adjusted R^2= variance accounted for if derived from the population from which the sample was taken (Fields, 2005) (* p< 0.05, **p<0.01, ***p<0.001).

3.3.8 Falls

Participants were initially asked to report the number of falls in the previous 12 months. As can be seen in Figure 3.10a, while 96% of the sample reported between zero and ten falls during this period, two participants reported a significantly higher fall frequency. Figure 3.10b shows the frequency distribution with the two outliers removed. To limit the effect of these outliers on our results, the falls data were dichotomised into the following groups: individuals who had reported at least one fall in the previous 12 months, and those who had not fallen at all during this period. As the descriptive statistics in Table 3.1 show, 44% of participants reported falling at least once in the previous 12 months.

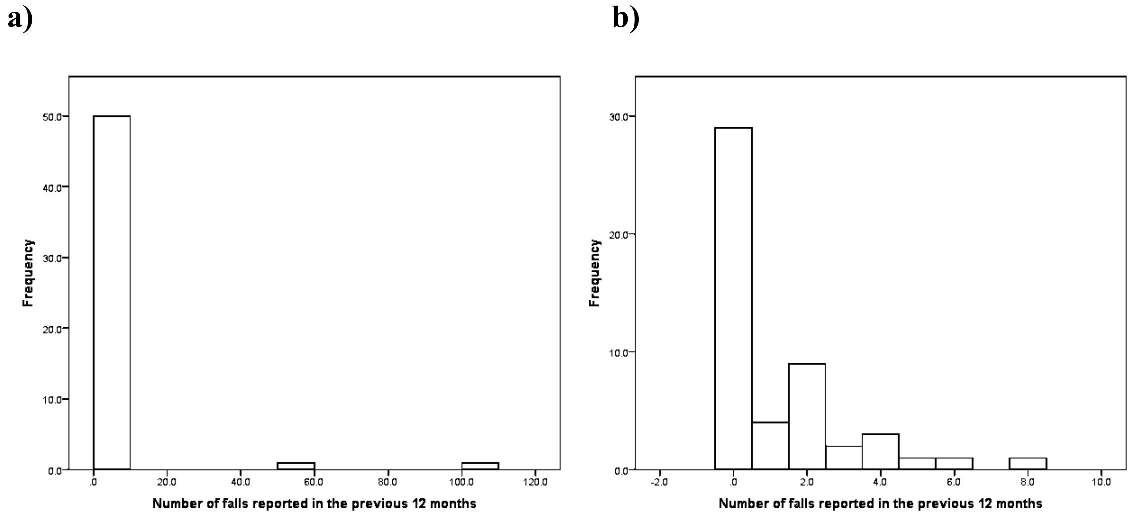


Figure 3.10 Graphic representation of the frequency of falls in the previous 12 months (a) in the entire the same, (b) with two outliers removed.

The falls data were compared to all the continuous demographic and clinical variables in Mann-Whitney U tests to establish whether the means of the independent samples significantly differed between those who had and had not fallen. There were no statistically significant differences at the Bonferroni corrected p value ($p<0.003$) between participants who had reported a fall in the previous 12 months and those who had not for any of the variables assessed. At the 95% significance level however, the only demographic or clinical function variables to significantly differ between those who had and had not fallen were the overall (0-60 deg) ($U=214.50$, $p=0.028$), peripheral (30-60) deg) ($U=192.50$, $p=0.009$), and inferior (0-60 deg) ($U=211.00$, $p=0.024$) visual field scores; with greater visual field loss in participants who reported a fall.

	Have you fallen in the past 12 months?
Demographic variables	
Gender	U=311.50
Use of mobility aids	U=277.50
Use of low vision aids	U=300.50
Living arrangements	U=309.50
Current employment status	U=254.00
Sight loss registration	U=262.50
Age	U=292.00
Duration of visual impairment	U=309.00
Number of medications	U=319.50
Number of comorbidities	U=326.00
Clinical function variables	
Binocular VA (LogMAR)	U=312.50
Binocular CS (LogCS)	U=294.00
Binocular reading acuity (LogMAR)	U=327.00
Visual function variables	
Overall visual field (0-60 deg) (dB)	U=214.50
Central visual field (0-30 deg) (dB)	U=226.50
Peripheral visual field (30-60 deg) (dB)	U=192.50
Superior visual field (0-60 deg) (dB)	U=229.50
Inferior visual field (0-60 deg) (dB)	U=211.00
Self-reported function	
Overall self-reported function	U=225.00
Mobility self-reported function	U=208.50

Table 3.20 Relationship between the variables assessed, and fall history. Mann-Whitney U tests were conducted ($p \geq 0.003$ for all).

3.3.9 ROC analysis

Mobility was the most reported difficult domain of the D-AI in ordinal analysis ($\bar{x}$=2.14 ±0.13). The two goals underlying this domain that were reported most difficult were self-reported mobility difficulty indoors ($\bar{x}$=2.50 ±0.17) and outdoors ($\bar{x}$=2.37 ±0.17) in unfamiliar surroundings. The difficulty of twelve mobility related activities underlying these goals was also asked of participants. As the descriptive statistics in Table 3.21 illustrate, orientation in poor light was the most difficult reported task underlying both goals (indoors: $\bar{x}$=2.21(±1.26) and outdoors: $\bar{x}$=2.29(±1.23)).

	Mean(±std)	Median(25%IQ-75% IQ)
Mobility function indoors in unfamiliar surroundings		
Orientate in poor light indoors	2.21(±1.26)	3.00(2.00-3.00)
Find your way in very bright light (e.g. glare of lamps)	1.79(±1.42)	2.00(1.00-3.00)
Walk around safely, without tripping over things (e.g. doorsteps)	1.79(±1.21)	2.00(1.00-3.00)
Walk around safely, without bumping into things (e.g. furniture, doors)	1.62(±1.40)	2.00(1.00-3.00)
Walk down stairs safely	1.37(±1.19)	2.00(0.00-3.00)
Walk up stairs safely	0.98(±1.00)	1.00(0.00-2.00)
Mobility function outdoors		
Orientate and find your way in poor light outside	2.29(±1.23)	3.00(2.00-3.00)
Walk around safely without hitting overhanging things (e.g. branches)	2.06(±1.36)	3.00(1.00-3.00)
Find your way in very bright light (e.g. glare of car lights or the sun)	2.00(±1.19)	2.00(2.00-3.00)
Walk around safely without bumping into, tripping over, or stepping off something	1.87(±1.19)	2.00(1.00-3.00)
Notice other road users (e.g. cyclists, cars and pedestrians)	1.77(±1.26)	2.00(1.00-3.00)
Notice roadblocks in time (e.g. street furniture and road works)	1.50(±1.35)	2.00(1.00-3.00)

Table 3.21 Descriptive statistics of the mobility task question responses. Higher scores indicate greater difficulty.

Responses to these task questions were not Rasch analysed but instead were dichotomised to allow for an ROC (Receiver operating characteristic) analysis. Respondents were separated into the following two groups: those who reported difficulty with the mobility task (i.e. levels 2- slightly difficult to 5-impossible), and those who reported no difficulty (1- no difficulty). Each question was considered separately, with the participants' dichotomised responses acting as a classification of whether perceived difficulty with each mobility task was reported. Areas under the curves that are significantly different from 0.5 at the 95% confidence interval are highlighted in Table 3.22, and suggest visual field areas that are able to distinguish between participants who report difficulty with a mobility task and those who do not (Schoonjans, 2017).

Different areas of the visual field were compared to evaluate how effective they were at selecting participants with perceived mobility difficulty (sensitivity), and without perceived mobility difficulty (specificity). The sensitivity and specificity was determined for all possibly cut off values for the visual field scores. These were then plotted as a receiver operating characteristic (ROC) curve. The ROC curves for the different field areas were plotted on the same graph to allow for the comparison between the diagnostic precision of the different field scores using the area under the ROC curve. An area under the ROC curve of 1 indicates a perfect diagnostic procedure, whereas 0.5 indicates a poor procedure. A statistical technique described by DeLong et al., (1988) and appropriate where two measures are applied to the same set of participants, was used to compare areas under the ROC curves and establish if any visual field test was statistically significantly better at predicting perceived difficulty.

The exploratory plots' co-ordinate values were then examined to determine Youden's J statistic using the formula J = Sensitivity + Specificity - 1 (Youden, 1950; Schisterman et al., 2005; Powers, 2011). This allowed the criterion for selecting the optimum cut-off point that would indicate perceived mobility difficulty to be estimated, and also summarized the performance of the visual field as a diagnostic test. A value of 1 indicates that there are no false positives or false negatives, and a zero value indicates a test that gives the same proportion of positive results regardless of whether difficulty with a task is reported.

	Visual field area	AUC	x (optimal cut-off point, dB)	Sensitivity	Specificity	Youden's J
Mobility function indoors in unfamiliar surroundings						
Orientate in poor light indoors	0-60deg	0.97(±0.02)*	22.65	0.96	1.00	0.96
	0-30deg	0.97(±0.02)*	22.55	0.93	1.00	0.93
	30-60deg	0.98(±0.02)*	17.29	0.93	1.00	0.93
	Total superior	0.96(±0.03)*	19.24	0.89	1.00	0.89
	Total inferior	0.99(±0.01)*	24.55	0.98	1.00	0.98
Find your way in very bright light (e.g. glare of lamps)	0-60deg	0.80(±0.08)*	22.07	0.95	0.64	0.59
	0-30deg	0.77(±0.08)*	25.55	0.95	0.64	0.59
	30-60deg	0.82(±0.07)*	10.68	0.76	0.86	0.62
	Total superior	0.78(±0.08)*	23.13	0.92	0.64	0.56
	Total inferior	0.76(±0.10)*	18.14	0.82	0.75	0.57
Walk around safely, without tripping over things (e.g. doorsteps)	0-60deg	0.79(±0.12)*	16.55	0.75	0.88	0.63
	0-30deg	0.79(±0.11)*	23.63	0.82	0.75	0.57
	30-60deg	0.80(±0.10)*	13.12	0.77	0.88	0.65
	Total superior	0.76(±0.10)*	18.14	0.82	0.88	0.69
	Total inferior	0.83(±0.11)*	22.39	0.82	0.88	0.69
Walk around safely, without bumping into things (e.g. furniture, doors)	0-60deg	0.89(±0.06)*	15.57	0.86	0.94	0.80
	0-30deg	0.88(±0.06)*	18.76	0.81	0.94	0.74
	30-60deg	0.89(±0.06)*	10.51	0.78	0.94	0.72
	Total superior	0.86(±0.06)*	17.20	0.89	0.75	0.64
	Total inferior	0.89(±0.06)*	14.76	0.81	0.94	0.74
Walk down stairs safely	0-60deg	0.76(±0.08)*	21.29	0.94	0.59	0.53
	0-30deg	0.76(±0.08)*	24.09	0.91	0.59	0.50
	30-60deg	0.76(±0.08)*	12.22	0.80	0.71	0.51
	Total superior	0.72(±0.08)*	18.14	0.88	0.50	0.38
	Total inferior	0.77(±0.07)*	17.75	0.81	0.70	0.51
Walk up stairs safely	0-60deg	0.75(±0.07)*	16.36	0.81	0.65	0.46
	0-30deg	0.74(±0.07)*	21.03	0.78	0.60	0.38

	30-60deg	0.77(±0.08)*	10.68	0.81	0.75	0.56
	Total superior	0.73(±0.08)*	19.24	0.91	0.59	0.50
	Total inferior	0.78(±0.08)*	19.70	0.80	0.71	0.51
Mobility function outdoors						
Orientate and find your way in poor light outside	0-60deg	0.96(±0.03)*	22.65	0.93	1.00	0.93
	0-30deg	0.97(±0.02)*	25.55	0.91	1.00	0.91
	30-60deg	0.96(±0.03)*	17.29	0.91	1.00	0.91
	Total superior	0.94(±0.03)*	19.24	0.87	1.00	0.87
	Total inferior	0.99(±0.01)*	24.55	0.96	1.00	0.96
Walk around safely without hitting overhanging things (e.g. branches)	0-60deg	0.91(±0.06)*	23.35	0.98	0.78	0.76
	0-30deg	0.89(±0.07)*	27.27	0.95	0.78	0.73
	30-60deg	0.94(±0.03)*	16.21	0.91	0.89	0.80
	Total superior	0.91(±0.05)*	18.14	0.86	0.89	0.75
	Total inferior	0.91(±0.06)*	22.39	0.84	0.89	0.73
Find your way in very bright light (e.g. glare of car lights or the sun)	0-60deg	0.82(±0.07)*	16.36	0.73	0.88	0.60
	0-30deg	0.78(±0.09)*	18.76	0.66	0.88	0.53
	30-60deg	0.84(±0.06)*	10.68	0.71	1.00	0.71
	Total superior	0.78(±0.08)*	7.68	0.55	1.00	0.55
	Total inferior	0.83(±0.07)*	17.75	0.71	0.88	0.58
Walk around safely without bumping into, tripping over, or stepping off something	0-60deg	0.92(±0.05)*	23.35	0.96	0.86	0.81
	0-30deg	0.92(±0.05)*	27.27	0.93	0.86	0.79
	30-60deg	0.91(±0.05)*	17.29	0.89	0.86	0.75
	Total superior	0.93(±0.04)*	17.20	0.80	1.00	0.80
	Total inferior	0.93(±0.05)*	24.55	0.93	0.86	0.79
Notice other road users (e.g. cyclists, cars and pedestrians)	0-60deg	0.91(±0.05)*	17.69	0.83	0.91	0.74
	0-30deg	0.88(±0.06)*	21.59	0.81	0.91	0.71
	30-60deg	0.94(±0.03)*	14.38	0.89	0.91	0.79
	Total superior	0.90(±0.05)*	18.14	0.88	0.82	0.70
	Total inferior	0.91(±0.05)*	22.04	0.85	0.91	0.76
	0-60deg	0.89(±0.05)*	16.55	0.86	0.81	0.67

Notice roadblocks in time (e.g. street furniture and road works)	0-30deg	0.89(±0.05)*	25.55	0.97	0.63	0.60
	30-60deg	0.91(±0.04)*	12.22	0.86	0.88	0.74
	Total superior	0.86(±0.06)*	18.14	0.92	0.67	0.60
	Total inferior	0.92(±0.04)*	19.70	0.86	0.89	0.74

Table 3.22 Receiver operating characteristics (ROC) areas under the curves (AUC) describing the relative performance of the overall (0-60deg), central (0-30deg), and peripheral (30-60deg) visual field in predicting self-reported function in mobility related tasks. Also provided are the calculated sensitivity and specificity values for each task question, and optimal discrimination points as determined by Youden's J statistic (J= Sensitivity+ Specificity -1). *indicates AUCs that are significantly ($p \leq 0.05$) different from 0.50.

The areas under the ROC curves for the central and peripheral visual field suggest both areas are good indicators of self-reported function in mobility tasks indoors and outdoors (Table 3.24). Areas under the curves for both the central and peripheral visual field were significantly different from 0.5 at the 95% confidence interval for all mobility tasks, indicating that both field areas were able to distinguish between participants who report difficulty with the mobility task and those who do not. There is no statistically significantly difference between the areas under the ROC curves for any of the 12 mobility questions.

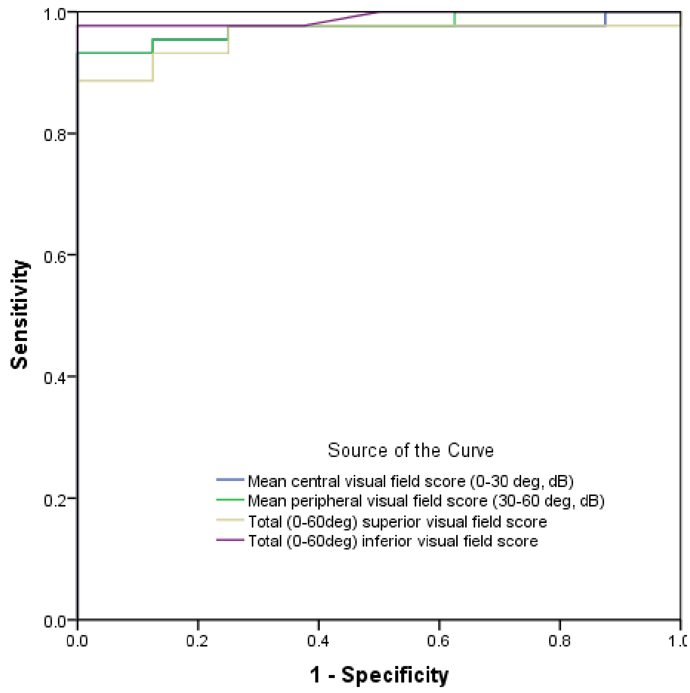
The optimal cut-off point for predicting perceived mobility indoors and outdoors, estimated using Youden's J, was higher for the central visual field compared with the peripheral field for all mobility tasks. The central field score cut-off point optimised to predict self-reported difficulty walking indoors without bumping into things for example is 18.76dB (J=0.76), suggesting individuals with a central field score of < 18.75dB will report difficulty with this task (sensitivity=0.81, specificity=0.94), compared with a peripheral field score of 10.51dB (J=0.72, sensitivity=0.78, specificity=0.94). Similar optimal cut-off points were determined for other task questions. The optimal discrimination point for the central visual field varied between 18.76 and 25.55dB and on average, participants with a central field score of < 23.10dB (±2.71) reported difficulty with mobility related tasks. In comparison, the average optimal cut off point for the peripheral visual field is 12.42dB (±2.61), and values vary between 10.51 and 17.29dB.

Additional ROC curves were plotted to investigate the efficacy of the total (0-60 deg) superior and inferior visual field areas at predicting self-reported mobility difficulty. The areas under the curves suggest that both the superior and inferior visual field are good at predicting perceived mobility difficulty indoors and outdoors, and AUCs were significantly different from 0.5 at the 95% confidence interval for all mobility tasks. The inferior visual field was found to be statistically significantly better at predicting difficulty orientating in bright light outside when compared with the superior visual field ($z=2.05$, $p=0.0401$). No other significant differences between areas under the ROC curves were found with other mobility tasks.

It was hypothesised that self-reported difficulty walking indoors without tripping over things would be better predicted by the inferior visual field. Both the superior and inferior visual field gave similar areas under the curve (AUC) however (superior: AUC=0.76(±0.10), inferior: AUC=0.83(±0.11), suggesting both field areas are similarly good predictors of perceived difficulty with this task. The optimal discrimination points for the two visual field areas suggest that participants lost a greater degree of superior visual field before reporting difficulty with this mobility task ($\bar{x}$=18.14dB, J=0.57). Participants perceived difficulty with a lesser degree of inferior field loss ($\bar{x}$=22.39dB, J=0.69), suggesting that difficulty with this task is reported sooner with inferior visual field loss. This may indicate the significance of the inferior field at predicted self-reported function with this task, and reflects the slight tendency for the inferior fields to be better related to perceived mobility function than the superior field in previous bivariate regression analyses.

Similarly, although the superior visual field was predicted to be a better indicator of self-reported difficulty walking outdoors without hitting overhanging things, there is no significant difference in the diagnostic efficacy of the two field areas (superior: AUC=0.91(±0.05), inferior: AUC=0.91(±0.06). Furthermore, the optimal discrimination points do not suggest that participants report difficulty with this task sooner with superior as compared with inferior field loss (superior x=18.14dB, J=0.75; inferior $\bar{x}$=24.55dB, J=0.73).

Is it difficult to orientate in poor light indoors?



Central field score

AUC=0.97(±0.02)

Peripheral field score

AUC=0.98(±0.02)

Superior field score

AUC=0.96(±0.03)

Inferior field score

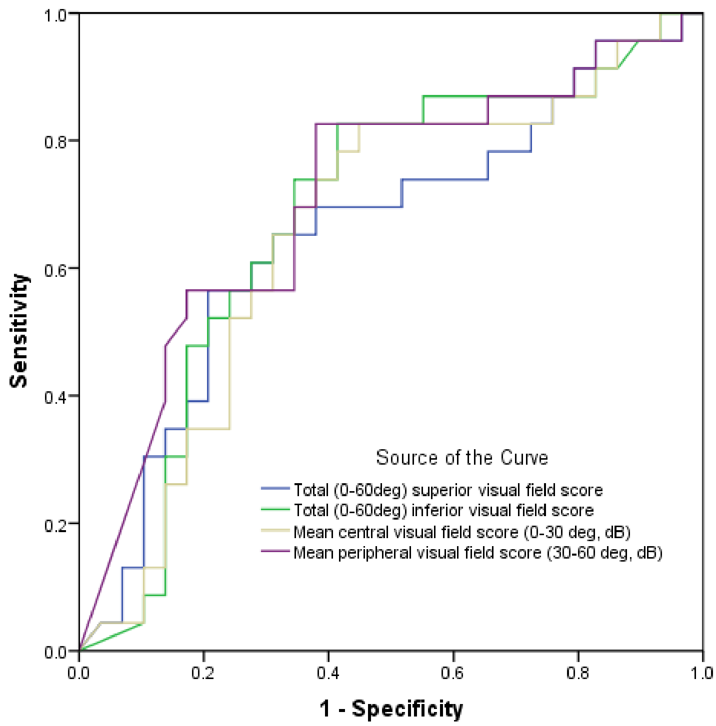
AUC=0.99(±0.01)

Figure 3.11 Receiver operating characteristics (ROC) curves describing the relative performance of the central, peripheral, superior and inferior visual field in predicting self-reported difficulty orientating in poor lights indoors. The area under the ROC curve is given for the different visual field areas.

Both Youden's J statistics, and the areas under the curve (AUC) indicate that the overall visual field (0-60deg) is a good predictor of mobility tasks, in particular navigating in poor light indoors (J=0.96, AUC=0.97(±0.02)), and outdoors (J=0.93, AUC=0.96(±0.03)) (Table 3.22). The optimal cut-off points, as determined by Youden's J statistic, suggest that for half of the task questions, participants lost a similar degree of overall field (cut-off points between 15.57dB-17.69dB) before reporting mobility difficulties. For some mobility tasks however, including orientation in poor light indoors and outdoors, the optimal cut-off point was greater ($\bar{x}$=22.65dB for both) suggesting that participants demonstrated difficulty with these tasks with a lesser degree of visual field loss.

To determine how effective the visual field is at predicting fall history, a further ROC curve was plotted (Figure 3.12). The area under the curve suggests that the overall (0-60 deg) visual field is at best a moderate predictor of fall history (AUC=0.68(±0.08), $p<0.001$). Similar areas under the curve were also found with more specific areas of the visual field. The low Youden's J statistics (0.36-0.45) also suggest that the visual field is a poor diagnostic test to predict fall incidence. Although there are no significant differences between the areas under the ROC curves for any of the visual field areas, the AUC for the central and superior visual field were not significantly different from 0.5 at the 95% confidence interval ($p=0.051$ and $p=0.055$ respectively) indicating that these field areas were unable to significantly distinguish between participants who report falling the previous 12 months and those who do not, unlike the peripheral and inferior field (Table 3.12).

Have you fallen in the previous 12 months?



Visual field area	AUC	x (optimal cut-off point, dB)	Sensitivity	Specificity	Youden's J
0-60deg	0.68(±0.08)*	12.04	0.74	0.66	0.39
0-30deg	0.66(±0.08)	20.87	0.83	0.55	0.38
30-60deg	0.71(±0.07)*	10.58	0.83	0.62	0.45
Total superior	0.66(±0.08)	3.55	0.57	0.79	0.36
Total inferior	0.68(±0.08)*	15.74	0.83	0.59	0.41

Figure 3.12 Receiver operating characteristics (ROC) curves describing the relative performance of the overall (0-60deg) visual field in predicting if a participant had reported a fall in the previous 12 months. The area under the ROC curve is given. Also provided are the calculated sensitivity and specificity values for each task question, and optimal discrimination points as determined by Youden's J statistic. *indicates AUCs that are significantly ($p \leq 0.05$) different from 0.50.

3.4 Discussion

The purpose of this experiment was to relate different areas of the visual field to self-reported function in order to inform the determination of the most appropriate method of assessing the functional visual field in individuals with low vision. A binocular threshold test that tests out to 60 degrees can represent the functional abilities of individuals with peripheral visual impairment.

3.4.1 Demographic variables

The demographic variables provide a description of the sample's general characteristics. Given the inclusion criteria, the sample reflects principal causes of peripheral visual field loss. Glaucoma accounted for the greatest proportion of the current sample (42%), reflecting the leading cause of peripheral visual loss in a study of the prevalence of visual field loss in an elderly population (Ramrattan et al., 2001). 40% of the current sample reported retinitis pigmentosa as the primary ocular diagnosis. This is consistent with Liew et al., (2014) who found that hereditary retinal disorders including retinitis pigmentosa are the leading cause of sight loss certification in England and Wales in the working population. The range and proportion of ocular diagnoses reported by the sample however differs greatly from the overall data of individuals registered as sight impaired or severely sight impaired in the UK (Brunce & Wormald, 2006) and to other UK low vision rehabilitation care providers (Lindsay et al., 2004; Crossland & Silver, 2005), and is not representative of the UK low vision population. This is due to the exclusion of individuals with isolated central visual field loss, namely macular dysfunction, which accounts for 55% of visual impairment certificates in the UK (Bruce & Wormald, 2006). The mean age of 59 years is younger than that reported in other low vision studies (Tabrett & Latham, 2012), and by low vision service providers (Harper et al., 1999; Lindsay et al., 2004), and is more consistent with other studies of RP and glaucoma participants. (Haymes et al., 1996; Szlyk et al., 1997; Seo et al., 2009; Sugawara et al., 2009; Asaoka et al., 2011). It is has been suggested that primary open angle glaucoma may be more prevalent in men (de Voogd et al., 2005; Dielemans et al., 1994; Mukesh et al., 2002), and although a gender predilection has not been identified in retinitis pigmentosa, X-linked RP is expressed more severely in men, who are affected slightly more than women (Fahim et al., 2000). These factors may explain the discrepancy between the proportion of males (60%) and females (40%) in the sample.

The median duration of visual impairment for the sample was 15 years indicating established visual impairment. The proportion of participants who report using a mobility aid (39%) is similar to that found in a study of mixed low vision patients (Lamoureux et al., 2010). Almost half of the sample reported studying or being employed (46%), which is likely greater that the proportion reported in other low vision studies or by low vision service providers with an older demographic.

In the current sample sight impairment registration status was found to relate to overall self-reported function (R^2=0.52, $p<0.001$), where participants registered as severely sight impaired reported greater overall difficulty. There was also a weaker relationship between overall self-reported function and the duration of visual impairment, where participants with longstanding visual impairment reported greater overall difficulty (R^2= 0.16, p=0.003). This reflects the findings of Haymes et al., (2002). The use of both low vision and mobility aids were associated with greater self-reported function. The use of these aids may indicate a greater degree of vision impairment, resulting in worse perceived function. Although it is possible that this relationship may suggest that the aids do not reduce perceived difficulty, it is likely that the perception of difficulty remains even if the low vision and mobility aids are helpful.

The relationships between self-reported function and the demographic variables were otherwise not statistically significant. Similarly to Haymes et al., (2002), associations between self-reported function, and gender and living arrangements were not found. Haymes et al., (2002) did however find that greater age significantly predicted worse overall visual function, perhaps reflecting the functional decline which can occur with age (Elliott et al., 1990; Elliott & Bullimore, 1993; Rubin et al., 1997; 2001; Haymes et al., 2006). However, over half of our sample reported age-independent primary ocular diagnoses, and age was only weakly association with the degree of visual field loss (R^2=0.12, p=0.012). Consequently, and similarly to Travis et al., (2004) and Hazel et al., (2000), age was not found to correlate with self-reported function. Despite the documented relationship between exposure to certain medications, particularly those with sedative and anti-cholinergic actions, and the physical and mental function in the elderly population (Gray et al., 2003; Landi et al., 2007), an association between self-reported function and the number of medications reported was not found in our sample. The relationship between the number of sedative and anti-cholinergic medication and perceived function was also investigated. Globe et al., (2005) suggests an association between self-reported systemic comorbidities and self-reported visual function, particularly at more severe levels of visual impairment. This was not found in the current sample, perhaps reflecting the younger mean age of participants in the current sample, and their relative good health, as indicated by the low number of comorbidities.

3.4.2 Other clinical variables

As expected, worse clinical visual function is significantly associated with poorer self-reported visual function. The association between visual acuity and contrast sensitivity and functional vision that is found in the current sample has been demonstrated in numerous other studies (Owsley et al., 1981; Ross et al., 1985; Abrahamsson & Sjostrand, 1986; Owsley & Sloane, 1987; Lennerstrand & Ahlstrom, 1989; West et al., 2002). Seo et al., (2009) and Sumi et al., (2000) found a similar correlation between visual acuity and overall self-reported function using a 35 item questionnaire (Sumi et al., 1995) in a sample of RP participants as compared with the current sample (R^2=0.60, $p<0.001$ and R^2=0.53, $p<0.001$ respectively). The strong relationship between binocular CS and overall self-reported function may reflect the importance of a high contrast target to achieve optimum visual performance (Whittaker & Lovie-Kitchin, 1993), and a decreased tolerance to reduced contrast associated with vision loss (Rubin & Legge, 1989). Furthermore, Crossland et al., (2005) suggests that contrast sensitivity may predict future reading performance, and Leat & Woodhouse (1993) and Tabrett & Latham (2012) suggest that it may predict compensated reading performance. Binocular CS was also found to significantly relate to self-reported mobility function (R^2=0.38, $p<0.001$). A similar relationship was found by Haymes et al., (1996) who compared binocular CS measured with a Pelli-Robson chart to mobility function as assessed on two indoor mobility courses in a sample of individuals with RP (R^2=0.41-0.55, $p<0.001$). All reading performance variables were found to significantly to overall self-reported function, in particular binocular reading acuity (R^2= 0.54, $p<0.001$).

3.4.3 Visual fields

The fixation accuracy noted in our sample also corresponds well to fixation accuracy determined in previous studies that employed the test programs under normal, monocular conditions. Between 56% and 89% of subjects in one study (visually impaired and normally sighted), were recorded as having good fixation, or made less than 30% fixation losses (Katz & Sommer, 1988). Unlike Bengtsson & Heijl (2000), fixation accuracy was found to be significantly associated with field loss severity (R^2=0.20, p<0.001). A greater number of false negative responses have been found to indicate both a greater degree of glaucomatous loss, and poorer test reliability (Bengtsson & Heijl, 2000). Our data did not find this. Although false negative statistics were not significantly associated with the degree of visual field loss (R^2=0.00, p=0.896), greater visual field loss was found to relate to a greater number of false positives (R^2=0.39, p<0.001). This may suggest a relationship between field loss severity and the reliability statistics, reflecting the findings of Birt et al., (1997).

A large number of studies have attempted to relate visual field loss to functional difficulty. The majority of these studies however use conventional monocular visual fields tests that do not reflect the binocular field (Gutierrez et al., 1997; Parrish et al., 1997; El-Gasim et al., 2013). Other studies have assessed the visual field using a monocular threshold test, then determined artificially calculated sensitivity values by constructing a binocular field plot (Crabb & Viswanathan, 2004; Asaoka et al., 2012; Crabb et al., 2013). In this study actual threshold values were determined. Of the few studies that have assessed the visual field binocularly, the majority have assessed the visual field out to 30 degrees (Black et al., 1996; Tabrett & Latham, 2012). There are a handful of studies that assess the binocular visual field past 30 degrees, however these use kinetic (Lovie-Kitchin et al., 1990) and suprathreshold test strategies, such as the Esterman visual field test (Noe et al., 2003). The absolute threshold sensitivities of the peripheral visual field were not determined. This study builds on previous work that also used a threshold paradigm to assess the binocular visual field (Tabrett & Latham, 2012) by extending consideration of the visual field out to 60 degrees.

As predicted and discussed in previous chapters, and reflecting the findings of other studies, greater visual field loss is significantly associated with poorer self-reported visual function (Szlyk et al., 1997; Ramrattan et al., 2001; Tabrett & Latham 2012; El Gasim et al., 2013). In the current sample, the overall visual field is particularly strongly related to self-reported mobility function. Similarly, the visual field has been shown to be an important predictor of self-reported mobility difficulty in individuals with visual impairment (Bibby et al., 1996; Szlyk et al., 1997; Nelson et al., 2003; West et al., 2005; Tabrett & Latham, 2011; Tabrett & Latham, 2012), and RP (Haymes et al., 1996). It has been suggested that although visual acuity is necessary for activities such as reading small print, it is only weakly associated with the ability to navigate safely and independently in unfamiliar environments (Marron & Bailey, 1982; Brown et al., 1986). The visual field is similarly related to overall self-reported function as compared with visual acuity in the current sample (R^2=0.51, p<0.001 and R^2=0.52, p<0.001 respectively). The visual field however is a better indicator of self-reported mobility function than visual acuity as the stronger correlations indicate (R^2= 0.64, p<0.001 and R^2=0.40, p<0.001 respectively). A visual field variable was also repeatedly selected as the primary predictor of self-reported mobility function in stepwise multiple regressions. The superiority of the visual field over other measures of clinical function in predicting self-reported mobility function supports the findings of Tabrett & Latham (2011) who suggest that the visual field is better than visual acuity and contrast sensitivity at predicting self-reported mobility function in a sample of individuals with low vision. Lovie-Kitchin et al., (1990) also suggests that the visual field better predicts mobility performance compared with visual acuity and contrast sensitivity.

3.4.3.1 Central vs peripheral

To investigate the relationship between different areas of the visual field and self-reported function, the visual field was divided into the two following areas: the central visual field is defined as the central 0-30 degrees from fixation, and the peripheral visual field is defined as the peripheral 30-60 degrees. The central and peripheral visual field are highly correlated in the current sample (R^2=0.85, $p<0.001$), and both areas are also similarly related to overall function (central R^2=0.49, $p<0.001$ and peripheral R^2=0.48, $p<0.001$) indicating the importance of the entire visual field (0-60 degrees) and suggesting that both the central and peripheral visual field areas are important to consider when determining functional ability. The areas under the ROC curves for the central and peripheral visual field also suggest both areas are good indicators of self-reported mobility function indoors (central $\bar{x}$=0.85 ±0.08); peripheral $\bar{x}$=0.88 ±0.08), and there are no statistical difference between the areas under the ROC curves for any of the mobility tasks.

3.4.3.2 Overall sample

In overall multiple regression analyses including the entire sample of participants, the peripheral (30-60 deg) visual field and binocular CS combined explained 59% of the variance in the overall self-reported function. This reflects the findings of Haymes et al., (2002) who reported that visual field function and contrast sensitivity were included in the best predictive regression model explaining 45% variance of self-reported responses in nine mixed visual tasks in a heterogeneous sample. The omission of visual acuity from the best predictive models in the study by Haymes et al., (2002) may reflect the lack of specific reading tasks incorporated in their outcome measure. It may also reflect the nature of vision loss in the current sample; participants demonstrated peripheral rather than central field loss.

A multiple regression analysis using the entire sample and investigating the unique variance in self-reported mobility function explained by clinical function variables found that all of the 67% of explained variance was accounted for by the binocular peripheral visual field and binocular CS. This supports previous research that has shown that while visual acuity, visual field, and contrast sensitivity correlate significantly with mobility performance, the visual field and contrast sensitivity are stronger predictors than visual acuity (Marron & Bailey 1982; Bailey et al., 1993; Kuyk et al., 1998; Hassan et al., 2002). Similarly, Turano et al., (1999) found in individuals with RP that perceived visual ability for independent mobility was covariant with contrast sensitivity and monocularly assessed visual fields, but not visual acuity. The combined effect of the visual field and contrast sensitivity in other studies of low vision groups has been shown to account for 39% (Long et al., 1990) and 64% (Haymes et al., 1996) of the variance in measured mobility performance. Comparable to Black et al., (1997), both these studies also indicate a greater degree of variance being accounted for than that explained by either measure alone, suggesting the combined loss of visual function, as commonly seen in low vision practice, causes greater reductions in mobility. Black et al., (1997) found, in subjects with RP, that average visual field extent accounted for between 50% and 70% of the variance in the mobility measures, and between 54% and 75% with the inclusion of other vision measures. Similarly in another study, 64% of the variance in mobility performance in a sample of RP participants was found to be explained by a combination of visual fields and contrast sensitivity (Geruschat et al., 1998). The remaining unaccounted variance in the regression analyses are likely due to a combination of measurement errors, visual capabilities not measured in the study, and other factors such as personality.

In the present study, the selection of the peripheral visual field in these analyses suggests the importance of the peripheral visual field for overall self-reported function in mixed visual tasks, and not just mobility related tasks. This indicates that a good peripheral visual field is primarily responsible for efficient performance in overall visual related activities, contradicting the suggestions of other studies that indicate the superiority of the central visual field for overall function in activities of daily living. However, self-reported function is potentially dependant on questionnaire items. The relationship between central visual function and the peripheral visual field has been discussed in previous studies. Aspinall et al., (2005; 2008) found that glaucoma patients were more concerned about their central vision, despite the disease being characterised by peripheral visual field loss. They also found that as residual peripheral vision is reduced, the patient's priority rating of the central vision increased, and suggest that self-reported task importance of individuals with glaucoma is not predicted from the severity of glaucomatous visual field loss. This may extend to a glaucoma patient's self-reported function; if glaucoma patients place more importance on central vision tasks, then it is likely they will be more acutely aware of small changes to their central visual function, and increasingly so with progressing peripheral visual field loss.

The selection of the peripheral visual field also confirms the importance of the peripheral visual field for mobility related tasks, as previously discussed. Other studies suggest that mobility performance is likely to be worse with peripheral visual field loss rather than central field loss (Turano et al., 2004; Freeman et al., 2007). Freeman et al., (2007), who investigated the effect of impaired visual field on the risk of falling, reports that losses in peripheral visual field (20 -

60 degrees) are a more important risk factor for falling. Turano et al., (2004) also showed that peripheral visual impairment between 20 and 60 degrees is associated with an increasing risk of tripping over obstacles. The significance of the peripheral visual field to mobility function is however disputed by findings of other studies. Hassan et al., (2007) assessed navigation performance in normally sighted subjects with their field of view constricted to 10, 20 and 40 degrees in diameter, and suggest that the only the central 30 degrees is required for mobility function, even in low contrast conditions. Another study assessed the visual field to 90 degrees and proposed that only the central 37 degrees of the visual field is required for mobility function in individuals with low vision (Lovie-Kitchin et al., 1990), while Tabrett & Latham (2012) only assessed the central 30 degrees, and suggest that the best predictor of self-reported mobility function is the central 10-30 degrees of the visual field.

3.4.3.3 Better visual fields

While the relationship between the visual field and self-reported function was not found to depend on eccentricity, it may be influenced by the severity of the visual field loss. In individuals with a lesser degree of visual field loss (0-60 degrees mean threshold ≥10dB), the peripheral visual field was selected as the best predictor of self-reported mobility function, accounting for 38% of the variance in the results. This is consistent with previous studies and confirms the significance of the visual field (Marron & Bailey, 1982; Brown et al., 1986; Lovie-Kitchin et al., 1990; Haymes et al., 1996; Geruschat et al., 1998; Kuyk et al., 1998; Tabrett & Latham, 2011), in predicting mobility function in individuals with low vision. The results of the regression analysis are comparable to previous research that has also implemented multivariate analyses. Marron & Bailey (1982) found that the visual field extent of their heterogeneous low vision group accounted for 30% of mobility performance. Haymes et al., (1996), using an outdoor course and a sample of individuals with RP, found that the visual field accounted for 59% of the variance in mobility performance. Similarly, Lovie-Kitchin et al., (1990) found that 70% of the variance in mobility performance on a complex indoor course was explained by the binocular visual field in a small, mixed low vision group. Long et al., (1990) also using a heterogeneous low vision sample, found that only 14% of mobility performance was explained by visual field extent. The differences in the degrees of variance in mobility performance explained by the visual field in these studies could be due to different mobility measures, visual field assessment methods, and constitution of the low vision groups. While Haymes et al., (1996) used an indoor course, and Lovie-Kitchin et al., (1990) used an outdoor course to assess mobility performance, both Long et al., (1990) and Marron & Bailey (1982) used a combination of indoor and outdoor courses. Marron & Bailey (1982) tested the monocular 80 degree visual field extent on a tangent screen, Lovie-Kitchin et al., (1990) used an arc perimeter to measure the binocular visual field, Long et al., (1990) tested binocularly a 140 degree visual field extent with a bowl perimeter, and Haymes et al., (1996) assessed binocular kinetic fields on a Goldmann perimeter using a large bright target. It might be expected that, since they used subjects with peripheral field loss due to RP, Haymes et al., (1996) would find that the visual field explains a greater proportion of variance in mobility performance, unlike other studies who used heterogeneous low groups (Marron & Bailey, 1982; Long et al., 1990).

The selection of the peripheral visual field in particular in this analysis of those with better fields also supports previous studies that suggest the importance of the peripheral visual field for mobility related tasks. Mobility performance has been shown to relate more strongly to peripheral visual field loss rather than central field loss (Turano et al., 2004; Freeman et al., 2007). In a population sample of elderly individuals, Turano et al., (2004) investigated the effect of impaired visual field on mobility performance and showed that peripheral visual field (20-60 degrees) impairment more significantly associated with an increased risk of tripping over obstacles when compared with the central (0-20 degrees) visual field.

3.4.3.4 Worse visual fields

For participants with a greater degree of visual field loss (0-60 degrees mean threshold <10dB), binocular CS, the only selected variable, was found to account for 36% of the variance in self-reported mobility function. The selection of CS may be in part due to differences in the predominant ocular diagnosis in each of the better and worse visual field groups, as discussed previously. 76% of participants defined as having 'worse visual fields' reported RP as their primary ocular diagnosis, and a further 10% reported glaucoma. Reduced contrast sensitivity has been demonstrated in studies of individuals with RP (Lindberg et al., 1981) and glaucoma (Hawkins et al., 2003; McKendrick et al., 2007). Peak contrast sensitivity has been shown to explain some variability in mobility performance in low vision subjects. Comparable to the degree of variance found in the current sample, Marron & Bailey (1982) found that peak contrast sensitivity accounted for 32% of variance in mobility performance. Similarly Haymes et al., (1994) reported that contrast sensitivity accounted for 30% of variance in mobility performance of their subjects with simulated RP. Long et al., (1990) however, found that peak contrast sensitivity explained only 14% of variance in mobility performance in a heterogenous low vision group. The selection of binocular CS instead of a visual field variable as in the previous analysis with individuals with better visual fields could also reflect the restricted residual field data to assess in the worse field group. Further, the 6 degree spacing and the threshold paradigm does not distinguish between different levels of small residual fields. Other assessment techniques such as a kinetic method may be better at plotting and differentiating individuals with small remaining field areas.

The results of the current sample suggest that while the binocular visual field is a good predictor of perceived mobility function in individuals with an overall (0-60 degrees) average mean threshold of greater than 10dB, in individuals with a greater degree of field loss, the visual field (as measured here) becomes a poorer predictor of mobility function, and other clinical function measurements, namely contrast sensitivity, become important in indicating self-reported mobility ability.

Binocular CS was selected as the primary predictor of overall self-reported function in both participants with better and worse overall field scores, accounting for 43% and 52% of the variance in results respectively, reflecting the importance of assessing contrast sensitivity in patients with visual impairment.

3.4.3.5 Inferior visual field bias

Although the inferior visual field was found to account for most variance (61%) in self-reported mobility function, bivariate correlations suggest a similar relationship between the superior and inferior visual field areas, challenging the inferior field bias. There was a similar degree of association shown between the overall (0-60 degree) inferior and superior visual field areas and self-reported mobility function (R^2=0.56, $p<0.001$ superior, R^2=0.67, $p<0.001$ inferior). ROC curves were also plotted to investigate the efficacy of the total (0-60 deg) superior and inferior visual field areas at predicting self-reported mobility difficulty. The areas under the curves suggest that both the superior and inferior visual field are good at predicting perceived mobility difficulty indoors and outdoors, and no significant differences between were found between the areas under the ROC curves.

It was hypothesised that difficulty walking indoors without tripping over things would be better predicted by the inferior visual field. This was not the case in that the AUC suggested that both field areas are similarly good predictors of difficulty. However, when considering the optimal discrimination points, it can be observed that participants only reported difficulty with this mobility task once superior field sensitivity was below 18.14dB, whereas participants perceived difficulty when inferior field sensitivity fell below 22.39dB. These figures suggest that difficulty with this task is reported sooner with inferior visual field loss, consistent with the hypothesis that inferior field is of greater importance for self-reported function in this task.

Given the inferior field bias found in the literature for those with better visual fields, participants were divided into those with worse visual fields (<10dB), and those with better fields (≥10dB). While the superior and inferior visual field remain similarly correlated to perceived mobility function with participants with worse (<10dB) visual fields (overall superior R^2=0.43, $p<0.001$; overall inferior R^2=0.42, $p<0.001$), the inferior visual field was significantly and consistently better related to self-reported mobility function in those with better visual fields when compared with the superior visual field, and the superior visual field was consistently found to lose its significance to the Bonferroni corrected 0.8% level when correlated with mobility function (overall superior R^2=0.19, p=0.025; overall inferior R^2=0.45, $p<0.001$). This may suggest than the inferior visual field is only better at predicting mobility difficulties in individuals with a lesser degree of visual field loss.

Visual field loss in the inferior peripheral region (Turano et al., 2004; Marigold & Patla, 2008), and inferior mid-periphery (Lovie-Kitchin et al., 1990) adversely affect mobility more than loss of the visual field in other areas. This is due to the inferior field providing a stronger contribution to postural stability than the superior visual field (Black et al., 2008). It has also been suggested that the inferior visual field contributes a greater proportion of the visual information used in determining lower limb movements, foot placement, and obstacle detection (Marigold & Patla, 2008). Land (2006) suggests that individuals tend to fixate approximately two steps ahead when walking but loss of information from the lower visual field has been shown to reduce step length when walking across uneven terrain (Marigold & Patla, 2008).

Although the inferior visual field predicts self-reported mobility difficulty better than the superior visual field, this was not evident in individuals with an average threshold field score of <10dB. Therefore, there is no strong evidence for scoring the inferior visual field greater than the superior visual field in a functional field assessment. An ideal visual field test for a general low vision population will weigh the superior and inferior field areas similarly.

3.4.4 Fall frequency

Participants were initially asked to report the number of falls in the previous 12 months with the intention of using this as a continuous variable. However, to limit the effect of two outliers on the falls data, it was dichotomised into two groups: individuals who had reported at least one fall in the previous 12 months, and those who had not fallen at all during this period. 44% of participants reported falling at least once in the previous 12 months. None of the continuous demographic variables were found to significantly associate with falls, and of the clinical variables, a relationship was only found between the falls data and the visual field. At the 95%

significance level, rather than considering a Bonferroni corrected value, people who reported having fallen had slightly worse overall, peripheral, and inferior visual fields than those who had not fallen.

The differences between the peripheral and inferior, and superior and inferior visual field scores of those who had fallen, and those who had not although statistically significant, are weak. Although, the AUCs for the peripheral and inferior visual field were significantly different from at the 95% confidence interval, unlike the central and superior field areas, suggesting that the peripheral and inferior visual field are better predictors of fall history.

It is suspected that a limited relationship was found between the clinical function variables, in particular the visual field, and falls due to the poor recall of fall occurrence. An alternative method of quantifying the risk of falling that is more reliable, and relates better to clinical measures of function needs to be considered in the second experiment.

3.5 Conclusion

The results discussed in this chapter influence the protocol for the second experiment.

Greater visual field loss was associated with greater self-reported difficulty, suggesting that assessing the visual field binocularly using a threshold test strategy can represent the functional abilities of people with visual impairment. The strong correlation between the central and peripheral visual field scores, and the similar relationship between the field areas and overall self-reported function suggest that in order to accurately determine the functional consequences of visual field loss, it may be appropriate to assess beyond 30 degrees. The inferior visual field was found to predict self-reported mobility difficulty better than the superior visual field, but only in individuals with an average threshold field score of ≥10dB, and so an ideal visual field test for a general low vision population will weigh the superior and inferior field areas similarly.

Chapter 4

Experiment 1: Alternative Analyses

4.1 Introduction

The association between visual fields and functional ability in individuals with visual impairment has been discussed in previous chapters. It is not known however, what visual field assessment techniques are more effective at assessing the field in individuals with low vision. To provide a preliminary analysis of whether different visual field techniques or scoring procedures may be better at reflecting functional vision, different visual field scores were derived from the binocular threshold data outlined in Chapter 3 to try and determine the most appropriate method to assess peripheral functional visual fields as part of the low vision assessment.

Firstly, a cortical analysis of threshold visual field scores weighed the field data by cortical rather than retinal representation. Second and third analyses involved deriving suprathreshold and kinetic visual field scores from the threshold field data.

4.2 Results

4.2.1 Cortical threshold analysis

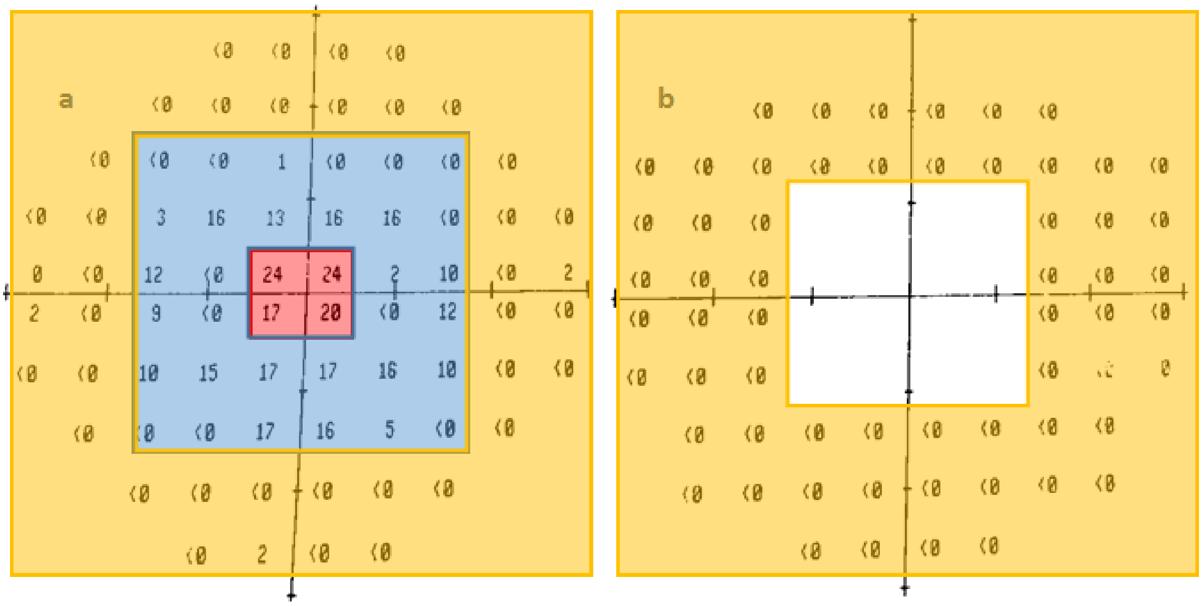


Figure 4.1 Example visual field results to demonstrate divisions of the visual field for cortical analysis. The central 0-4 degrees is highlighted by the red area, the blue area outlines the 4-16 degree band, and the yellow area indicates the 16-63 degree band. The absolute values provided by the HFA 30-2 and 60-4 programs were used to manually calculate the mean threshold of areas of the visual field.

The visual field data discussed in Chapter 3 is analysed reflecting the retinal distribution of the test points. Since the density of retinal ganglion cells decreases logarithmically with increasing eccentricity, and proportionally to the area of visual cortex per degree of the visual field (Rovamo & Virsu, 1979; Wassle et al., 1990), divisions of the field were made at eccentricities that followed a logarithmic progression to allow for a cortical analysis of the data (Haymes et al., 2002). The visual field was divided into three areas (0.4 deg, 4-16 deg and 16-63 deg), as

Figure 4.1 illustrates. Each band analysed would represent a similar amount of visual cortex processing as opposed to a constant retinal area. The mean thresholds of these three areas were calculated and used for analysis.

The peripheral 4-16 degree cortical band correlates highly with the central 0-30 retinal band (R^2=0.98, p<0.001), and the peripheral 16-63 degree cortical band correlates highly with the peripheral 30-60 retinal band (R^2=0.97, p<0.001). Consequently, while the cortical analysis of the visual field supports results from the retinal analysis, it failed to supplement existing findings. The peripheral 4-16 degree cortical area correlated similarly to overall self-reported function compared with the central (0-30 deg) retinal area (R^2=0.45, p<0.001 and R^2=0.49, p<0.001 respectively). Similar relationships were also found between mobility at goal level and the peripheral 16-63 degree cortical band and peripheral (30-60 deg) retinal band (R^2=0.64, p<0.001 and R^2=0.62, p<0.001 respectively); also reflecting the slight superiority of the peripheral visual field over the central field at predicting mobility related function. Complete results of the bivariate analyses performed on the cortical field data are provided in Table 4.1.

	Overall D-AI score	**Mobility function at goal level**
Central 4 deg	0.29*	0.32*
Peripheral 4-16 deg	0.45*	0.59*
Peripheral 16-63 deg	0.51*	0.64*

Table 4.1 Bivariate analysis between the cortical bands and self-reported visual function overall and mobility at goal level. Non parametric 2-tailed Spearman's correlations coefficients are used (*p<0.001).

4.2.2 Suprathreshold

A further analysis of the threshold visual field data involved converting the mean threshold values into dichotomous suprathreshold results. Test points with a threshold of ≥10dB were recorded as seen, and all points with a threshold value of <10dB were recorded as unseen (Figure 4.2). The suprathreshold visual field score was expressed as the total number of points seen in the overall visual field out of a possible 136. The number of points with a threshold of ≥10dB in the central visual field (0-30 deg) and the peripheral field (30-60 deg) was also calculated. To allow an investigation of the inferior visual field bias, a suprathreshold visual field score was also determined for superior and inferior areas of the visual field. A summary of this data is given in Table 4.2.

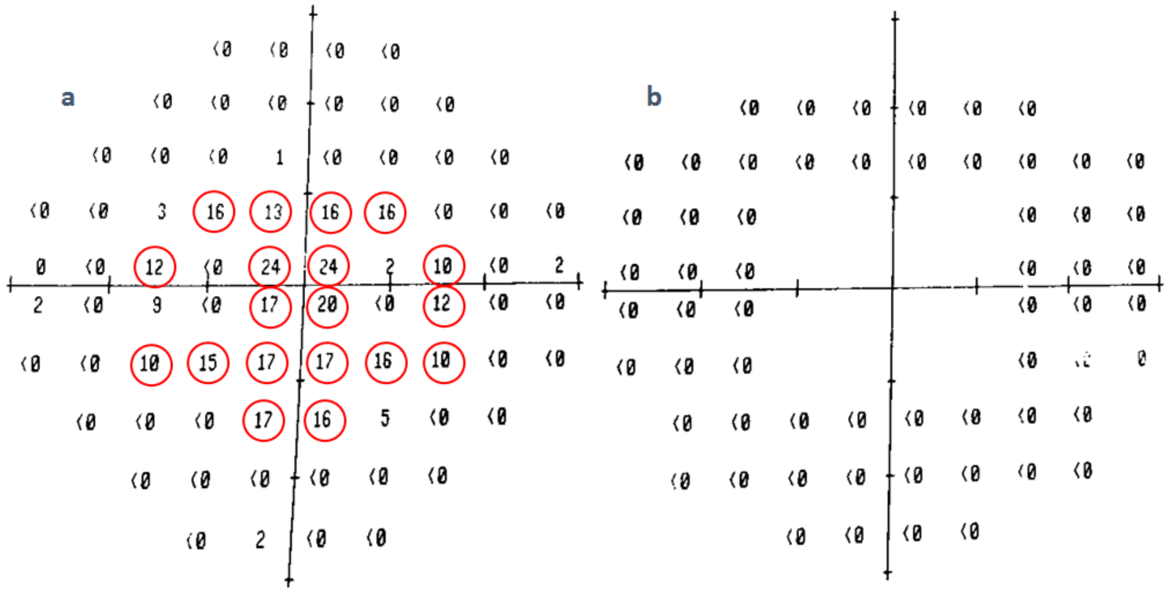


Figure 4.2 Example visual field results demonstrating how the suprathreshold visual field scores are calculated. All test points with a mean threshold of ≥10dB are recorded as seen, and are shown as the circled points on this diagram. All other points are recorded as unseen. The suprathreshold visual field score is the sum of all the points seen.

The stimulus intensity used to quantify the number of points seen to determine the suprathreshold visual field score is the same cut off value used in the previous retinal static field analysis to classify better and worse visual fields. 10dB is also the default intensity level used in single intensity screening tests of the HFA, and in the Esterman visual fields test as discussed in Chapter 1.

	Mean	**Median (25% IQ-75% IQ))**	**Range**	**Max possible score**
Total suprathreshold visual field score	68.02(±6.95)	76.00(11.00-121.00)	0-136	0-136
Central suprathreshold visual field score	42.13(±4.09)	46.50(10.00-73.00)	0-76	0-76
Peripheral suprathreshold visual field score	25.89(±3.09)	28.00(0.00-50.00)	0-60	0-60
Total superior (0-60 deg)	31.56(±3.43)	33.00(7.00-56.50)	0-66	0-66
Total Inferior (0-60 deg)	35.02(±3.94)	28.00(5.00-67.00)	0-70	0-70
Central superior (0-30 deg)	20.73(±2.18)	22.00(4.50-37.00)	0-38	0-38
Central inferior (0-30 deg)	20.75(±2.16)	17.00(4.50-37.50)	0-38	0-38
Peripheral superior (30-60 deg)	10.83(±1.42)	10.50(0.00-19.50)	0-28	0-28
Peripheral inferior (30-60 deg)	14.27(±1.88)	10.00(0.00-30.00)	0-32	0-32

Table 4.2 Descriptive statistics of the suprathreshold visual field scores.

The suprathreshold visual field scores are highly correlated with their full threshold equivalents. There is almost perfect correlation between the total suprathreshold visual field score and the overall threshold visual field score as Figure 4.3 demonstrates (R^2=0.98, p<0.001).

The suprathreshold visual field data were compared to self-reported function in bivariate analyses. As expected results of these analyses reflect the findings of the previous threshold field analysis. The total suprathreshold visual field score and the overall threshold field score related similarly to overall self-report (suprathreshold: R^2=0.49, p<0.001, threshold: R^2=0.50, p<0.001). Similar relationships were also found between the total suprathreshold visual field score and overall field score and mobility function at goal level (suprathreshold: R^2=0.63, p<0.001, threshold: R^2=0.64, p<0.001). Complete results of these bivariate analyses are provided in Table 4.3.

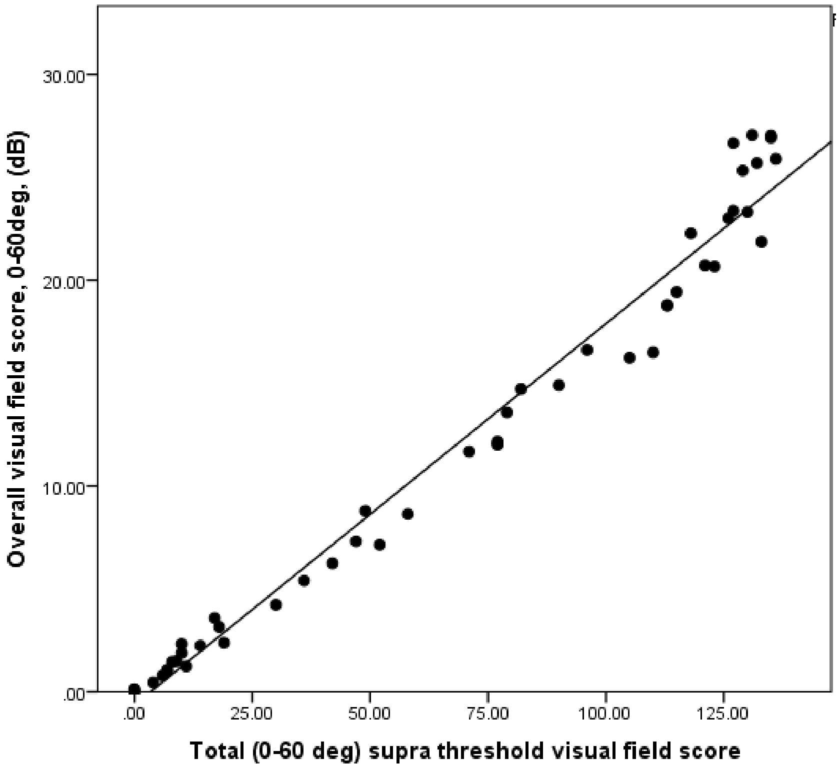


Figure 4.3 Graphical representation of the relationship between the overall visual field score (threshold), and the total suprathreshold visual field score (R^2=0.98, p<0.001).

	Overall D-AI score	Mobility function at goal level
Total suprathreshold visual field score	0.49*	0.63*
Central suprathreshold visual field score	0.50*	0.60*
Peripheral suprathreshold visual field score	0.44*	0.59*

Table 4.3 Bivariate analysis between the suprathreshold visual field scores and self-reported visual function overall and mobility at goal level. Non parametric 2-tailed Spearman's correlations coefficients are used (*p<0.001).

To investigate to the difference between the superior and the inferior suprathreshold visual field data, a suprathreshold visual field score was also determined for superior and inferior areas of the visual field. These areas were compared to overall and mobility related function in a bivariate analysis. The inferior and superior field scores are similarly correlated to overall and self-reported function. The overall superior and inferior suprathreshold visual field scores and the overall superior (suprathreshold: R^2=0.36, p<0.001, threshold: R^2=0.41, p<0.001) and inferior (suprathreshold: R^2=0.53, p<0.001, threshold: R^2=0.55, p<0.001) threshold fields scores related similarly to overall perceived function. Reflecting the results of previous threshold visual field analyses, the peripheral inferior visual field appears to be slightly better related to mobility function compared with the peripheral superior suprathreshold field, and the central field scores. Results of these bivariate analyses are provided in Table 4.4.

	Overall D-AI score	Mobility function at goal level
Total superior (0-60 deg)	0.36*	0.53*
Total Inferior (0-60 deg)	0.53*	0.65*
Central superior (0-30 deg)	0.39*	0.50*
Central inferior (0-30 deg)	0.52*	0.59*
Peripheral superior (30-60 deg)	0.28*	0.44*
Peripheral inferior (30-60 deg)	0.50*	0.63*

Table 4.4 Bivariate analysis comparing the suprathreshold superior and inferior visual field results with overall and mobility related self-reported function. Non parametric 2-tailed Spearman's correlations coefficients are used (*p<0.001).

A supplementary analysis using a decreased stimulus intensity (24dB) to calculate to the number of points seen and determine a suprathreshold field score was also performed. While it has been suggested a decreased suprathreshold stimulus intensity would expand the useful range of scores (Choy et al., 1986; Harris & Jacobs, 1995) an attempt at decreasing the Esterman stimulus intensity from 10dB to 20-26dB did not improve its ability to predict self-reported function (Jampel et al., 2002a). Results of this analysis were then compared with the previous 10dB suprathreshold analysis. The suprathreshold visual field scores calculated using 24dB and 10dB stimulus intensity were well correlated as the graphs in Figure 4.4 demonstrate. Furthermore, the total (0-60 deg) suprathreshold visual field score determined using a 24dB stimulus intensity related similarly to overall and mobility self-reported function as compared with a field score determined with a brighter 10dB target (Table 4.5). This suggests that decreased stimulus intensity may not improve the ability of a visual field test to predict self-reported function.

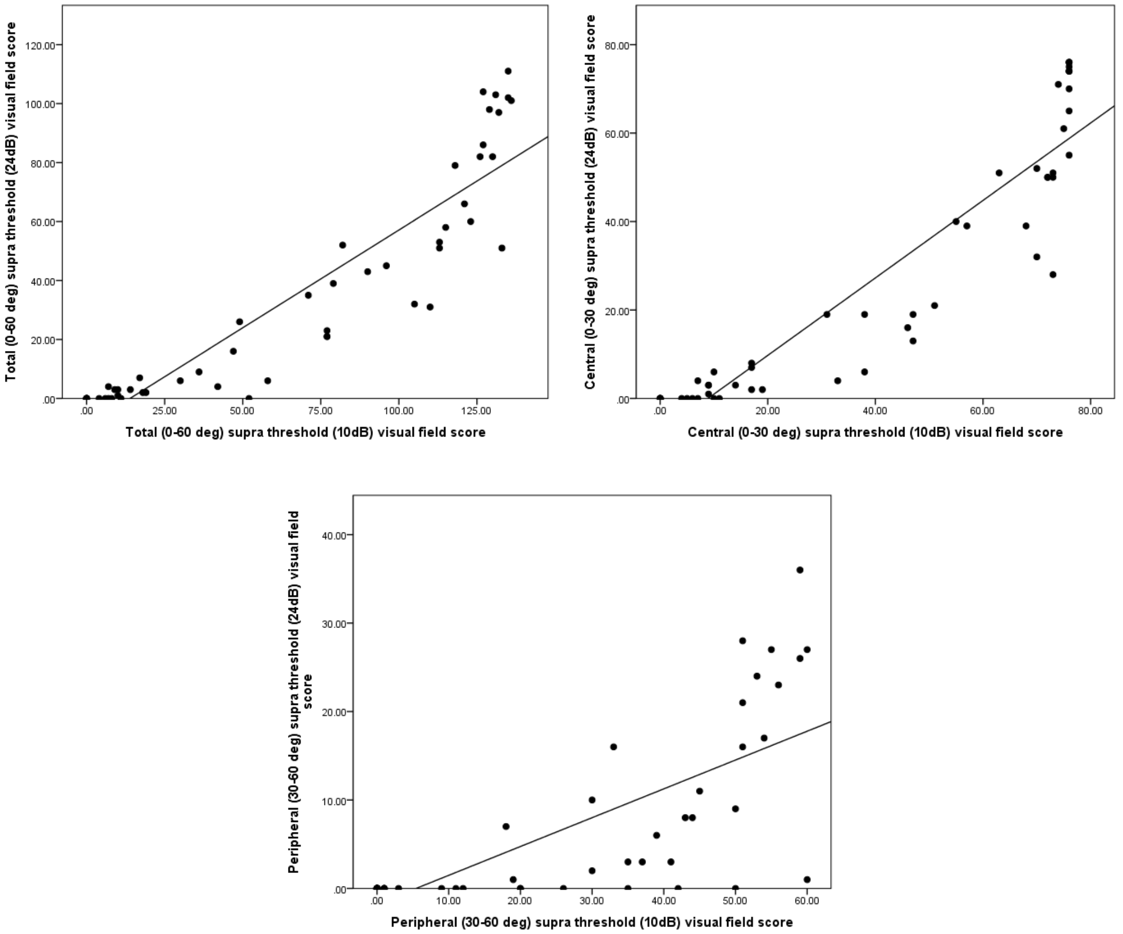


Figure 4.4 Graphical representations of the relationships between suprathreshold visual field scores determined with a 10dB and 24dB stimulus intensity. Different graphs represent different areas of the visual field.

	Overall D-AI score		Mobility function at goal level	
	10dB	24dB	10dB	24dB
Total (0-60 deg) suprathreshold visual field score	0.49*	0.46*	0.63*	0.53*
Central (0-30 deg) suprathreshold visual field score	0.50*	0.44*	0.60*	0.52*
Peripheral (30-60 deg) suprathreshold visual field score	0.44*	0.41*	0.59*	0.47*

Table 4.5 Bivariate analysis comparing the relationship between the two different suprathreshold visual field scores with overall and mobility self-reported function. Non parametric 2-tailed Spearman's correlation coefficients are used (*$p<0.001$).

4.2.3 Kinetic

The final alternative method of visual field data analysis was a derived kinetic analysis of the retinal static field data. Similarly to Black et al., (1997), the visual field extent along the eight principal meridians were averaged to give an overall average visual field extent in degrees (Figure 4.5). The average of the three superior and three inferior meridians was determined to investigate the significance of the superior and inferior field extent on self-reported mobility function. The extent at each meridian was determined as the midpoint between the last point with a mean threshold of ≥10dB, and the point at which the mean threshold was < 10dB (Figure 4.6). Finally the sum of the two horizontal, and the two vertical meridians were calculated to compare the effects of horizontal and vertical field restriction on self-reported mobility function. A summary of this data is given in Table 4.6.

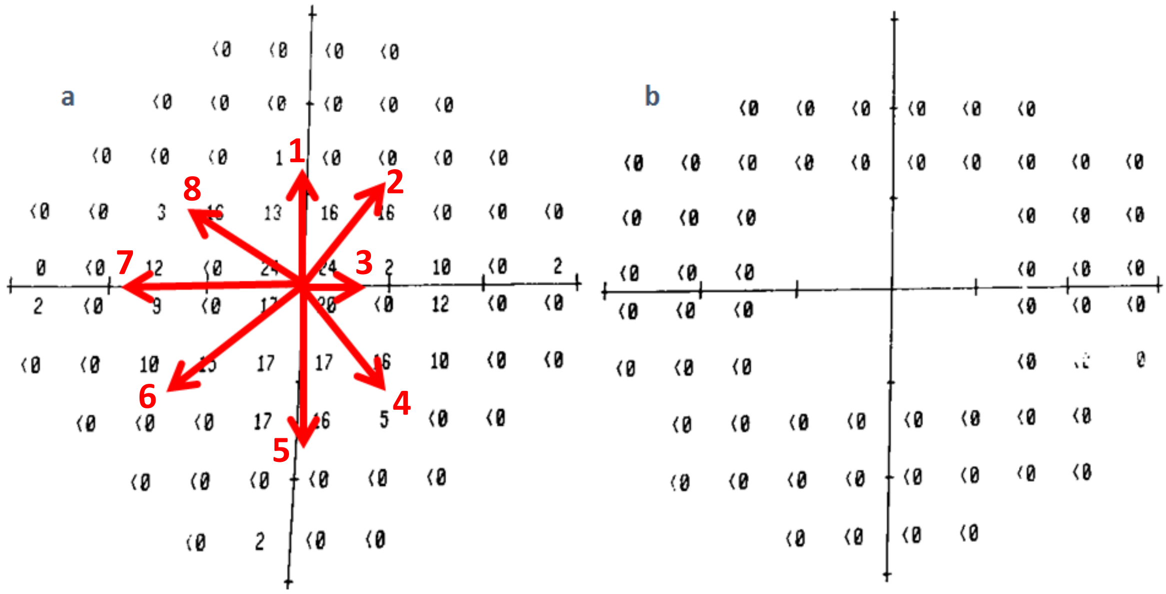


Figure 4.5 Example visual field results demonstrating how the kinetic field extent was derived. The average field extent was the average of all 8 meridians (1-8 in the diagram), the average superior extent was determined by calculating the average of meridians 8, 1 and 2, and the inferior by calculating the average of meridians 6, 5 and 4. The sum of the meridians 7 and 3 in the diagram, and meridians 1 and 5 were used to quantify horizontal and vertical extent respectively.

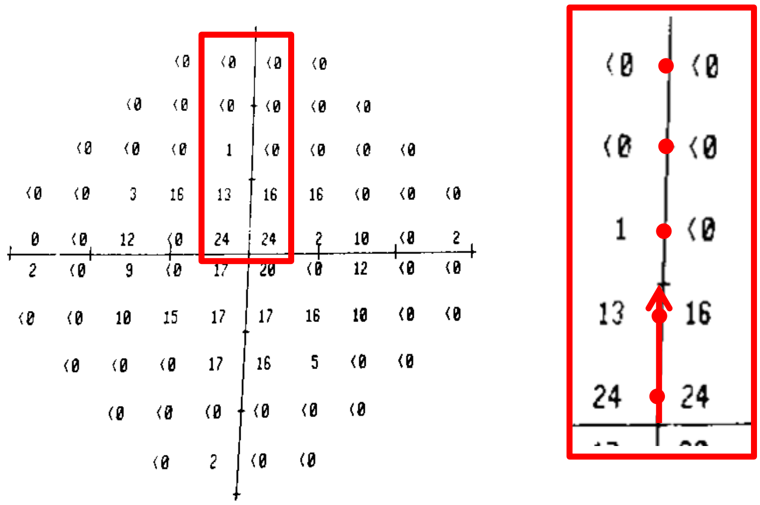


Figure 4.6 The extent at each meridian was determined as the midpoint between the last point with a mean threshold of ≥10dB, and the point at which the mean threshold was < 10dB. For example in this diagram since the point 9 degrees from fixation along the vertical meridian has a mean threshold of 13dB, but the next point along at 15 degrees has a mean threshold of 1dB, the extent along this meridian is recorded as 12 degrees.

The stimulus intensity used is also the same cut off value used in the previous retinal static field analysis to classify better and worse visual fields, and to quantify the suprathreshold visual field scores.

	Mean	Median (25% IQ-75% IQ))	Range	Max score possible
Average visual field extent (deg)	31.5(±2.52)	39.00(13.13-48.38)	0.00-49.50	0.00-49.50
Average superior field extent (deg)	26.48(±2.40)	28.00(12.00-43.00)	0.00-45.00	0.00-45.00
Average inferior field extent (deg)	30.92(±2.64)	37.50(11.00-49.00)	0.00-49.00	0.00-49.00
Total horizontal field extent (deg)	76.21(±5.96)	105.00(30.00-114.00)	0.00-114.00	0.00-114.00
Total vertical field extent (deg)	59.89(±5.19)	63.00(24.00-96.00)	0.00-102.00	0.00-102.00

Table 4.6 Descriptive statistics of the kinetic visual field extent data.

	Overall D-AI score	Mobility function at goal level
Average visual field extent (deg)	0.42*	0.56*
Average superior field extent (deg)	0.24*	0.39*
Average inferior field extent (deg)	0.47*	0.54*
Total horizontal field extent (deg)	0.44*	0.54*
Total vertical field extent (deg)	0.39*	0.56*

Table 4.7 Bivariate analysis between the kinetic visual field extent and self-reported visual function overall and mobility at goal level. Non parametric 2-tailed Spearman's correlations coefficients are used (*p<0.001).

The average visual field extent correlated strongly with the overall threshold visual field score (R^2=0.86, $p<0.001$), and accordingly similar relationships between the average field extent and self-reported function were found. There was a significant relationship between the average visual field extent and overall self-reported function (R^2=0.42, p<0.001), and mobility related function (R^2=0.56, p<0.001). Complete results of these bivariate analyses are provided in Table 4.7.

The average field extent of the three superior, and three inferior meridians were determined to investigate the significance of the kinetically assessed superior and inferior visual field on self-reported mobility function. Reflecting the results of previous analyses, although both the average superior and inferior field extents relate strongly to mobility function, the inferior visual field appears to be slightly better correlated (superior: R^2=0.39, p<0.001, inferior: R^2=0.54, p<0.001).

The sum of the two horizontal, and two vertical meridians was calculated to investigate the effect of horizontal and vertical field restriction on self-reported function. As Table 4.7 demonstrates both horizontal and vertical field extents are significantly related to overall and mobility related self-reported function, and both variables appear to be similar predictors of self-reported function.

4.2.4 Comparison of different visual field analyses

As the results of the bivariate analyses given in Table 4.8 and Figure 4.7 demonstrate, the visual field is significantly correlated with self-report, and in particular self-reported mobility function, regardless of the method of visual field analysis. Although the strongest correlations were found between self-report and the overall threshold visual field, a similarly significant relationship was found with the total suprathreshold visual field score, suggesting that little information is lost with a 10dB suprathreshold field assessment compared with a full threshold assessment.

	Overall D-AI score	Mobility function at goal level
Overall threshold visual field (dB)	0.50*	0.64*
Total 10dB suprathreshold visual field score	0.49*	0.63*
Average visual field extent (deg)	0.42*	0.56*

Table 4.8 Bivariate analysis comparing the different methods of visual field analysis with self-reported function. Non parametric 2-tailed Spearman's correlations coefficients are used (*p<0.001).

Results of the comparison between the visual field analyses confirms the significance of the visual field to self-reported mobility function irrespective of the method of field analysis. The suprathreshold visual field scores are highly correlated with their full threshold equivalents. There is almost perfect correlation between the total suprathreshold visual field score and the overall threshold visual field score as Figure 4.7 demonstrates (R^2=0.98, $p<0.001$). However the slightly weaker relationship between the kinetic field scores and both threshold and suprathreshold scores may suggest an overestimation of the visual field scores in some participants with the derivation of field extent. As demonstrated in Figure 4.7, there are three outlying points in the graph representing of the relationship between the suprathreshold and kinetic, and threshold and kinetic visual field scores. These points indicate participants whose kinetic field score, or average field extent is greater than their suprathreshold and threshold field score would predict.

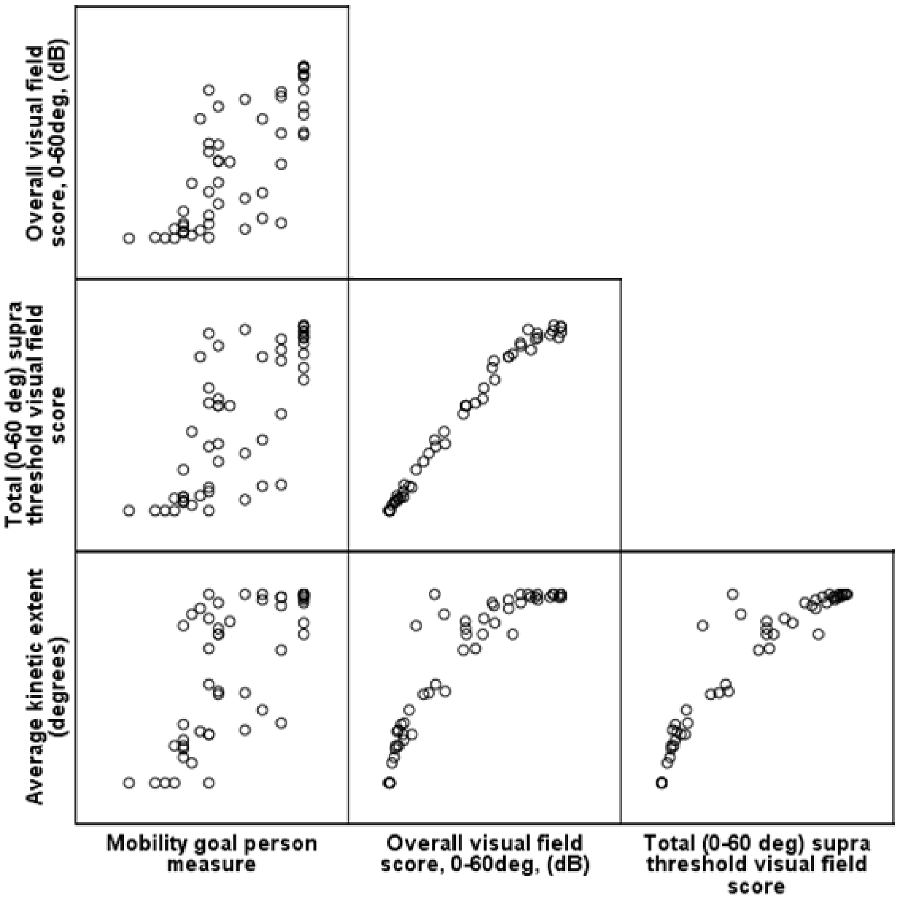


Figure 4.7 Graphical representations of the relationships between the different methods of field analyses (threshold (dB), suprathreshold (number of points seen), and kinetic (extent in deg) and self-reported mobility function (logits).

4.2.5 ROC analysis

ROC curves were also plotted to investigate the efficacy of derived suprathresold and kinetic visual field analyses at predicting self-reported mobility difficulty tasks. Responses to the twelve mobility related activities underlying the mobility goals were dichotomised as outlined in Chapter 3. Each question was considered separately, with the participants' dichotomised responses acting as a classification of whether perceived difficulty with each mobility task was reported. The areas under the curves (AUC), as well as the optimal cut-off point for predicting perceived mobility function was estimated using Youden's J (Table 4.9). Areas under the curves that are significantly different from 0.5 at the 95% confidence interval are highlighted in Table 4.9, and suggest visual field scores that are able to distinguish between participants who report difficulty with a mobility task and those who do not (Schoonjans, 2017).

Areas under the curves and Youden's J statistics indicate that the overall suprathreshold and kinetic visual field scores are good predictors of mobility tasks, in particular navigating in poor light indoors (suprathreshold: J=0.93, AUC=0.96(±0.03); kinetic: J=0.84, AUC=0.92(±0.04)), and outdoors (suprathreshold: J=0.91, AUC=0.94(±0.03); kinetic: J=0.82, AUC=0.90(±0.04)). The AUC for both the derived suprathreshold and kinetic field scores were significantly different from 0.5 at the 95% confidence interval for all mobility tasks. The optimal cut-off points, as determined by Youden's J statistic, suggest that participants lost between 7% and 31% ($\bar{x}$=18.93±3.27) of their suprathreshold visual field score before reporting mobility difficulty. Participants reported difficulty walking around outside safely without bumping into, tripping over, or stepping off something, and orientating in poor light indoors and outdoors with earlier/less restricted visual field loss. Participants could however lose 31.62% of their suprathreshold visual field score before reporting difficulty with orientating in bright light indoors and outdoors. Optimal discrimination points were also determined for the kinetic visual field scores. Across all mobility tasks, participants lost a small degree of field extent before perceiving difficulty (41.63-47.63 deg, $\bar{x}$=46.76±1.75, maximum value 52.5 deg).

The average areas under the curves of indicate that all three methods of analyses (threshold, suprathreshold and kinetic) are good at predicting perceived difficulty with mobility tasks (threshold AUC=0.86(±0.08), suprathreshold AUC=0.86(±0.08), and kinetic AUC=0.84(±0.09)). There are no significant differences between the areas under the ROC curves for any of the visual field scores, suggesting all three analyses are equally good predictors of self-reported mobility difficulty.

	Visual field variable	AUC	x (optimal cut-off point)	Sensitivity	Specificity	Youden's J
Mobility function indoors in unfamiliar surroundings						
Orientate in poor light indoors	Suprathreshold score (/136)	0.96(±0.03)*	124.50	0.93	1.00	0.93
	Average visual field extent	0.92(±0.04)*	47.63°	0.84	1.00	0.84
Find your way in very bright light (e.g. glare of lamps)	Suprathreshold score (/136)	0.80(±0.08)*	93.00	0.76	0.79	0.55
	Average visual field extent	0.82(±0.08)*	46.18°	0.82	0.79	0.60
Walk around safely, without tripping over things (e.g. doorsteps)	Suprathreshold score (/136)	0.77(±0.11)*	122.00	0.86	0.75	0.61
	Average visual field extent	0.75(±0.11)*	47.63°	0.80	0.75	0.75
Walk around safely, without bumping into things (e.g. furniture, doors)	Suprathreshold score (/136)	0.88(±0.06)*	93.00	0.86	0.94	0.80
	Average visual field extent	0.88(±0.06)*	46.13°	0.89	0.88	0.76
Walk down stairs safely	Suprathreshold score (/136)	0.76(±0.08)*	116.50	0.89	0.59	0.47
	Average visual field extent	0.72(±0.08)*	47.63°	0.86	0.59	0.45
Walk upstairs safely	Suprathreshold score (/136)	0.76(±0.07)*	93.00	0.78	0.65	0.43
	Average visual field extent	0.78(±0.07)*	47.63°	0.91	0.60	0.51
Mobility function outdoors						
Orientate and find your way in poor light outside	Suprathreshold score (/136)	0.94(±0.03)*	124.50	0.91	1.00	0.91
	Average visual field extent	0.90(±0.04)*	47.63°	0.82	1.00	0.82
Walk around safely without hitting overhanging things (e.g. branches)	Suprathreshold score (/136)	0.91(±0.05)*	122.00	0.91	0.89	0.80
	Average visual field extent	0.95(±0.03)*	47.63°	0.86	1.00	0.86
Find your way in very bright light (e.g. glare of car lights or the sun)	Suprathreshold score (/136)	0.80(±0.07)*	93.00	0.71	0.88	0.58
	Average visual field extent	0.85(±0.05)*	41.63°	0.66	1.00	0.66
Walk around safely without bumping into, tripping	Suprathreshold score (/136)	0.92(±0.04)*	126.50	0.91	0.86	0.77
	Average visual field extent	0.88(±0.05)*	46.13°	0.76	1.00	0.76

over, or stepping off something						
Notice other road users (e.g. cyclists, cars and pedestrians)	Suprathreshold score (/136)	0.93(±0.04)*	122.00	0.93	0.82	0.75
	Average visual field extent	0.96(±0.02)*	47.63°	0.90	1.00	0.90
Notice roadblocks in time (e.g. street furniture and road works)	Suprathreshold score (/136)	0.89(±0.05)*	93.00	0.81	0.81	0.62
	Average visual field extent	0.88(±0.05)*	47.63°	0.92	0.75	0.67

Table 4.9 Receiver operating characteristics (ROC) areas under the curves (AUC) describing the relative performance of the difference visual field scores in predicting self-reported function in mobility related tasks. Also provided are the calculated sensitivity and specificity values for each task question, and optimal discrimination points as determined by Youden's J statistic (J= Sensitivity+ Specificity -1). *indicates AUCs that are significantly ($p \leq 0.05$) different from 0.50.

4.3 Discussion

Data in Chapter 3 was presented considering the retinal representation of the visual field. However, since the density of retinal ganglion cells decreases logarithmically with increasing eccentricity, and proportionally to the area of visual cortex per degree of the visual field (Rovamo & Virsu, 1979; Wassle et al., 1990), divisions of the field were also made at eccentricities that followed a logarithmic progression to allow for a cortical analysis of the threshold data. This analysis is similar to that of Haymes et al., (1996) who devised a method to measure and score the residual visual field based on the approximate representation of the visual field in the cortex called Percentage of Total Visual Field. They assessed the binocular visual field beyond 64 degrees kinetically, and found that the residual field quantified in this manner correlated significantly to mobility performance (R^2=0.26-0.42, $p<0.05$). Such cortical analysis of the visual field has been shown to relate better to mobility performance than other methods of scoring the visual field (Esterman, 1982; Marron & Bailey, 1982; Arditi, 1988; Long et al., 1990; Lovie-Kitchin et al., 1990; Colenbrander et al., 1993; Szlyk et al., 1997, Carta et al., 1998; Geruschat et al., 1998; Kuyk et al., 1998). Haymes et al., (2002) attempted to improve the Total Visual Field method by using finer gradations. A similar relationship was found between this new method, The Anatomical Visual Field Score, and self-reported function and performance as determined with The Melbourne Low Vision ADL Index (R^2=0.31, $p<0.001$).

In the present analysis, the peripheral 4-16 degree cortical area correlated similarly to overall self-reported function compared with the central (0-30 deg) retinal area (R^2=0.45, $p<0.001$ and R^2=0.49, $p<0.001$ respectively). Similar relationships were also found between mobility function level and the peripheral 16-63 degree cortical band and peripheral (30-60 deg) retinal band (R^2=0.64, $p<0.001$ and R^2=0.62, $p<0.001$ respectively); also reflecting the slight superiority of the peripheral visual field over the central field at predicting mobility related function. These results are comparable to previous analyses that used retinal visual field bands, suggesting that a cortical analysis of the visual field has little to add over a conventional retinal analysis, and confirming the significance of the peripheral visual field to self-reported function irrespective of the method of field analysis.

A further analysis of the threshold visual field data involved converting the mean threshold values into dichotomous suprathreshold results. The number of points with a threshold of ≥10dB in the central visual field (0-30 deg) and the peripheral field (30-60 deg) was also calculated. The stimulus intensity used to quantify the number of points seen to determine the suprathreshold visual field score is the same cut off value used in the previous retinal static field analysis to classify better and worse visual fields. While it has been suggested a decreased suprathreshold stimulus intensity would expand the useful range of scores (Choy et al., 1986; Harris & Jacobs, 1995) a previous attempt at decreasing the Esterman stimulus intensity from 10dB to 20-26dB did not improve its ability to predict self-reported function (Jampel et al., 2002a). In the current study, a supplementary analysis using a decreased stimulus intensity (24dB) to calculate to the number of points seen and determine a suprathreshold field score was also performed. Results of this analysis were then compared with the previous 10dB suprathreshold analysis. The suprathreshold visual field scores calculated using a 24dB and 10dB stimulus intensity were highly correlated, and the total (0-60 deg) suprathreshold visual field score determined using a 24dB stimulus intensity related similarly to overall and mobility self-reported function as compared with a field score determined with a brighter 10dB target, suggesting a decreased stimulus intensity does not improve the ability of a visual fields test to predict self-reported function.

In the current study results of the suprathreshold visual field data reflect the findings of the previous threshold field analysis. The total suprathreshold visual field score and the overall threshold field score related similarly to overall self-report (suprathreshold: R^2=0.49, $p<0.001$, threshold: R^2=0.50, $p<0.001$). Similar relationships were also found between the total suprathreshold visual field score and overall field score and mobility function at goal level (suprathreshold: R^2=0.63, $p<0.001$, threshold: R^2=0.64, $p<0.001$). Numerous other studies which assessed the visual field using a binocular suprathreshold paradigm also suggest an association between the visual field and function as outlined in consideration of the Esterman assessment in Chapter 1.

A further analysis of the threshold visual field data involved a kinetic analysis of the retinal static field data. The average visual field extent correlated strongly with the overall threshold visual field score (R^2=0.86, $p<0.001$), and accordingly similar relationships between the average field extent and self-reported function were found. There was a significant relationship between the average visual field extent and overall self-reported function (R^2=0.42, $p<0.001$), and mobility related function (R^2=0.56, $p<0.001$). Similarly, other studies have found an association between the visual field assess kinetically and self-reported function (Haymes et al., 2002; Bibby et al., 2007), and mobility performance (Lovie-Kitchin et al., 1990; Haymes et al., 1996; Haymes et al., 2002; Lovie-Kitchin et al., 2010).

Considering derived kinetic scores for comparison to previous studies, optimal discrimination points, as determined by Youden's J statistic indicate that across all mobility tasks, participants lost only a small degree of field extent before perceiving difficulty with mobility related tasks (41.63-47.63 deg, $\bar{x}$=46.76±1.75, maximum value 52.5 deg), and suggest that early loss of visual field extent may predict mobility difficulties. This is contrary to the suggestions of other studies. Genensky (1976) investigated functional difficulties that certain visual field defects may be expected to cause and suggests the most serious mobility problems are observed in patients with visual fields smaller than 3 degrees. Similarly, Pelli (1986) proposes that mobility performance is only slightly impaired for visual fields as small as 4 degrees. Furthermore Faye (1984) states that a patient's orientation and mobility performance is not greatly impaired if they maintain 40 degrees of their visual field. Hassan et al., (2007) assessed navigation performance in 20 normally sighted subjects with their field of view constricted to 10, 20 and 40 degrees in diameter, and suggest that the field of view required for navigation is between 10.9 and 32.1 degrees depending on contrast conditions. Lovie-Kitchin et al., (1990) also assessed mobility performance on an indoor course, and assessed the binocular visual field out to 90 degrees on a Hablin Lister arc perimeter. They propose the central 37 degrees is most important for mobility function in individuals with low vision. Tabrett & Latham (2012), who assessed the central 30 degrees of the visual field, found that in a sample of low vision participants, the central 10-30 degrees of the visual field best predicts visual related activity limitation in mobility tasks. Similarly, Sumi et al., (2003) used the 30-2 test in glaucoma patients and reported that perceived function in mobility tasks was best explain by the function of the inferior 5 degrees from fixation. Conversely, it has also been suggested that a loss in the peripheral visual field can impede mobility function. Similarly to the current study, Freeman et al., (2007) suggests the importance of the peripheral visual field to mobility function. They found that in a population sample of older adults, the peripheral 20 to 60 degrees remained statistically significantly correlated with the risk of falling after they attempted to determine the independent associations of the central and peripheral visual field deficits, whereas the central visual field (0 -20 deg) lost its statistical significance. Geruschat et al., (1998) measured the monocular visual field of RP subjects by kinetic perimetry and defined visual field extent as a dichotomous variable that indicated whether the visual fields were contained within the central 20 degrees, or whether they extended beyond the central 20 degrees. They found the visual field extent significant correlated with mobility function as assessed on a mobility course, with worse function in subjects with fields contained within the central 20 degrees.

The visual field is significantly correlated with self-report and in particular self-reported mobility function, regardless of the method of visual field analysis. The total suprathreshold visual field score related similarly to self-reported function when compared with the overall threshold score, suggesting that that little information is lost with a 10dB suprathreshold field assessment compared with a full threshold assessment. While the suprathreshold visual field scores are highly correlated with their full threshold equivalents, there is a slightly weaker relationship between the kinetic field scores and both threshold visual field scores and suprathreshold scores. This may suggest an overestimation of the visual field scores in some participants with the derivation of field extent. These results suggest that a full threshold assessment of the visual field might have little to add over a quicker suprathreshold, or kinetic assessment.

Choy et al., (1986) compared difference visual field protocols including the Esterman visual fields tests, and the determination of visual field extent, and related results to self-reported function as assessed by a short 5-item questionnaire. Comparably to the current study, they found that perceived function related similarly to the different visual field scoring methods. Yanagisawa et al., (2011) also compared self-reported function, as determined by the NEI-VFQ, with different visual field protocols. These protocols include the AMA scoring system, the visual field quantified as a solid angle, the binocular Esterman visual field score, and the Functional Field Score. They found that only the Esterman field score correlated with self-reported function.

4.4 Conclusion

Cortical analysis, suprathreshold and kinetic field scores were derived from the threshold data. The results of these analyses confirm the significance of the peripheral and inferior visual field to self-reported mobility function irrespective of the methods of field score derivation. All three methods of derivation related similarly to self-reported function, and each explained a similar degree of variance in the data. This suggests that exploring the use of quicker tests than binocular threshold may be valuable in producing a functional field test that relates well to functional vision, but maybe quicker and more patient friendly. A limitation of this analysis is that data were not measured by these different methods but derived from the same threshold data set. The binocular visual field will be assessed using different paradigms in Experiment 2.

Chapter 5

Experiment 2: Visual Field Paradigms

5.1 Introduction

Results of Experiment 1 suggest that both the central and peripheral fields both have a role in reflecting the functional difficulties of people with field loss and should be considered in a functional visual field assessment. The significance of the inferior field to both mobility function and overall function was also demonstrated, although since this relationship was dependant on the degree of visual field loss, an ideal visual field test for a general low vision population will weigh the superior and inferior field areas similarly. Derived suprathreshold and kinetic field scores were derived from the threshold data and all three methods of derivation related similarly to self-reported function.

In this chapter, different visual field paradigms are compared to determine if a threshold method is preferable to alternative paradigms such as suprathreshold or kinetic fields in producing an outcome that can be used clinically and best describes functional difficulty. These tests are compared with existing methods described in Chapter 1 to determine the most appropriate method of assessing visual fields in the low vision assessment.

Although few studies have compared visual field methods to investigate their ability to reflect functional ability, comparisons are limited to the Esterman visual field test and conventional monocular threshold assessment (Turano et al., 1999) or IVF (Jampel et al., 2002a; Crabb & Viswanathan, 2004), or kinetic perimetry (Choy et al., 1986; Yanagisawa et al., 2012). The present study is the first to compare tests of all three paradigms (threshold, suprathreshold, and kinetic) with currently available assessments of the functional visual field.

5.2 Methods

5.2.1 Participants

The study was carried out at Anglia Ruskin University Eye Clinic. Thirty three individuals who participated in Experiment 1 returned to take part in the second study. Seventeen new participants were recruited using similar methods as previously discussed. A number of charities including RP Fighting Blindness and the International Glaucoma Association were also contacted to advertise the study on their social media pages and newsletters. Fifty participants in total with general peripheral field loss, for example due to pathologies such as glaucoma and retinitis pigmentosa were recruited in total. Participants with no measurable visual field function were excluded from the study. Exclusion criteria was as for Experiment 1. Ethical approval was granted by Anglia Ruskin University Research Ethics committee. All participants gave informed consent after the nature of the study was explained.

5.2.2 Demographics

As in Experiment 1, a series of structured demographic questions conducted in a face to face interview elicited key information including age, gender, cause of visual impairment, length of time since ocular diagnosis, registration status, living arrangements, current education or employment status and the presence of any comorbid conditions. Details of any prescribed medication were also recorded.

The Falls Efficacy Scale (FES) (Tinetti et al., 1990; Tinetti et al., 1994), and the Adelaide Activities Profile (AAP) (Clark & Bond, 1995) were also assessed, and responses to these instruments are discussed in Chapter 7.

5.2.3 Clinical function assessments

Habitual spectacle correction was focimetered and recorded, along with the type of any low vision and mobility aids used. The participants' interpupillary distance was measured for a fixed distance of 30cm.

High contrast visual acuity, contrast sensitivity, and near reading performance was assessed binocularly with methods described in Chapter 3.

5.2.4 Visual fields assessment

Five visual field assessments were performed using the Octopus 900 Perimeter (Haag-Streit International, AG, Koniz, Switzerland) and the Humphrey Field Analyser (Carl Zeiss Meditec, Inc., Dublin, CA).

For binocular assessments on the HFA the monocular test strategy for the right eye was utilised. The chin rest was positioned as far right as possible and the left hand side of the chin rest was used. The binocular setting on the Octopus 900 was selected. Participant's fixation was monitored manually (Black et al., 1996; Leat & Lovie-Kitchin 2006; Tabrett & Latham, 2012). To ensure binocularity was maintained, and since it was only possible to monitor the fixation of the RE, participants were reminded to keep both eyes open throughout the assessment. They were also invited to request a rest break should they find themselves inclined to close their non-dominant eye. Other reliability indices provided by the HFA and Octopus perimeters, including false positives and false negatives, and fixation losses for monocular tests were also reviewed. The test was stopped if during the first attempt false negative or false positive responses exceeded 50%, or if poor fixation was observed by the practitioner. The participant was reinstructed and a new test was then started. The subsequent test attempt was not interrupted if poor reliability indices or poor fixation was observed. All cases were used in subsequent analyses.

The standard size III Goldmann white stimulus was used in all tests. Participants fixated on the standard orange central point target on the HFA, and on green cross mark target on the Octopus 900. A 6 degree ring target was utilised on the Octopus, and an adaption to the fixation target on the HFA that slotted into the fixation target hole to provide a black 2mm high contrast pericentral ring around the fixation spot were used where necessary. The background luminance was 10cd/m^2 (31.5asb) in the HFA, and 31.4asb in the Octopus 900.

The three tests conducted on the Octopus 900 Perimeter were as follows:

1. Binocular threshold

   A custom test point pattern (Figure 5.1) and 2-phase test was used to assess the binocular visual field out to 60 degrees from fixation. The first phase of the test assesses the field out to 30 degrees with 52 points spaced 7.5 degrees apart. Full aperture trial lenses were used in adult half eye trial frames with lens centration distances corrected for near. The second test phase assesses the function of the peripheral 30-60 degrees of the visual field using 36 points spaced 15 degrees apart. Participants were asked to remove any near correction and performed the second test phase uncorrected to minimise the possibility of lens and frame artefacts. The spacing of the test points allowed for the quick and comprehensive assessment of the visual field out to approximately 60 degrees with 88 points, compared with the 136 points assessment in Experiment 1. Test points extended to approximately 55 degrees inferiorly, and laterally, and approximately 40 degrees superiorly. This reflects the anatomical field restriction superiorly, and is similar to existing visual field assessments such as the peripheral 60-4 on the HFA, and the Esterman test.

The low vision test strategy was utilised for this assessment. Stimuli are presented using a 4-2-1 dB bracketing test method starting at 0dB (4000asb) in order to arrive quickly at the expected threshold level in subjects with impaired visual fields. A longer 200ms stimulus duration, rather than the standard 100ms, is also applied. The absolute thresholds achieved at each test location were used to calculate the mean threshold (Figure 5.2) as in Experiment 1.

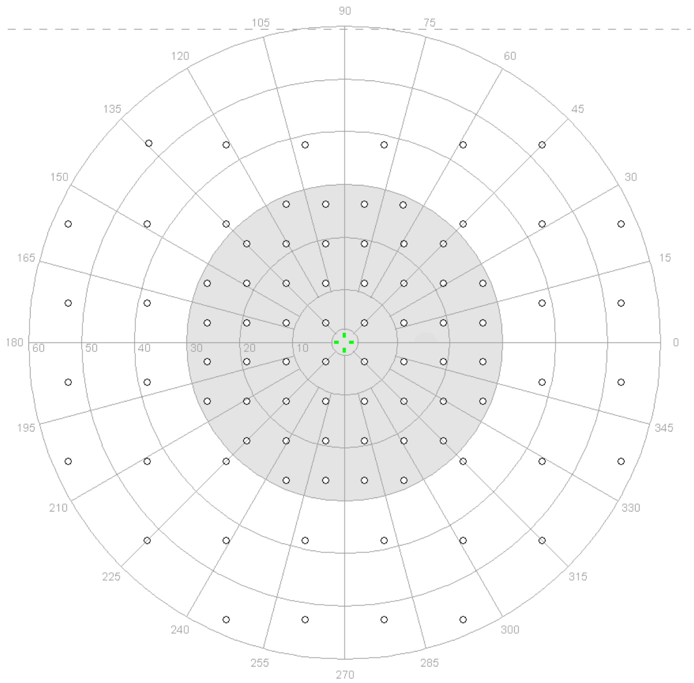


Figure 5.1 The custom test point pattern used in the binocular threshold, and binocular suprathreshold assessments. 88 points are spaced 7.5 deg apart in the central 30 deg, and 15 deg apart in the peripheral 30-60 deg.

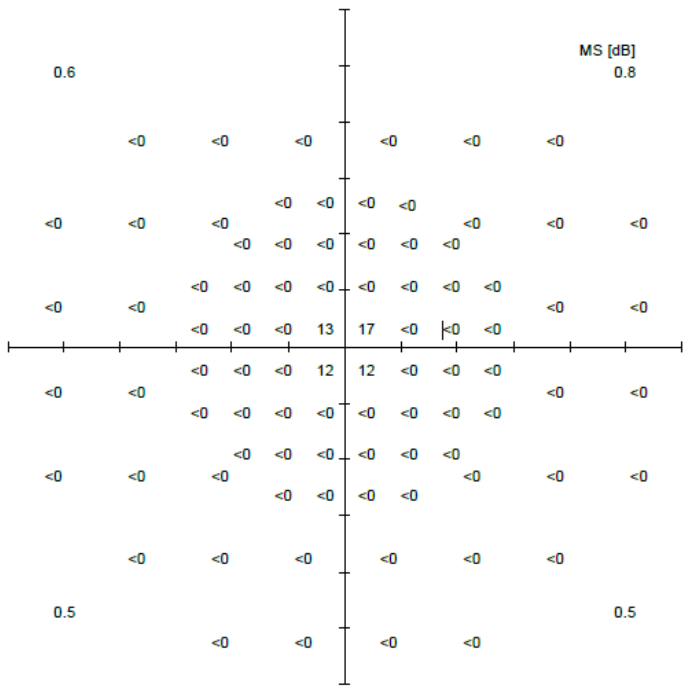


Figure 5.2 Binocular threshold visual field results of participant 12. Mean threshold scores were averaged to derive the binocular threshold field score (here $\bar{x}$ =0.61dB) used in subsequent analyses.

2. Binocular suprathreshold

The same custom test pattern (Figure 5.1) and 2 phase test protocol as the binocular threshold assessment was used. The 88 locations are assessed with a Goldmann size III white stimulus at intensity of 10dB. The stimulus intensity was chosen on the basis of the supplementary analyses in Experiment 1 which derived 10dB and 24dB suprathreshold scores from threshold data and suggest that a decreased stimulus intensity does not improve the efficacy of the visual field test at predicting perceived function over the standard value of 10dB. The number of points seen out of the total of 88 was used to calculate a percentage score (Figure 5.3).

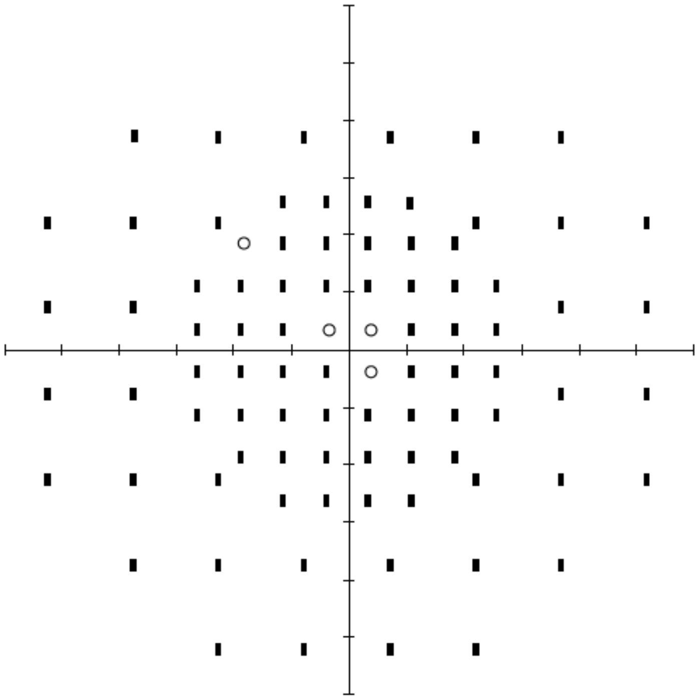


Figure 5.3 Binocular suprathreshold visual field results of participant 12. The percentage of points seen out of a total of 88 (here 5%) was used in subsequent analyses.

3. Binocular kinetic

Experiment 1 analyses using a kinetic field score derived from threshold data suggested that the visual field assessed kinetically out to 60 degrees provides a good indicator of self-reported function. A third test was designed to assess the central 60 degrees of the visual field using a white III-4e target at an angular velocity of 5 deg/sec. Vectors were presented from 60 degrees eccentricity and moved centrally in 12 meridians spaced every 30 degrees as illustrated in Figure 5.4.

This automated assessment was completed without correction to minimise the possibility of lens and frame artefacts. The solid angle (degrees^2) subtended by the isopter was determined automatically using the Eye Suite software (Figure 5.5) (Peters et al., 2013). The extent of visual field in degrees in each meridian was also used to calculate the average field extent (Quinn et al., 1996; Black et al., 1997). The perimeter corrected results for reaction time bias.

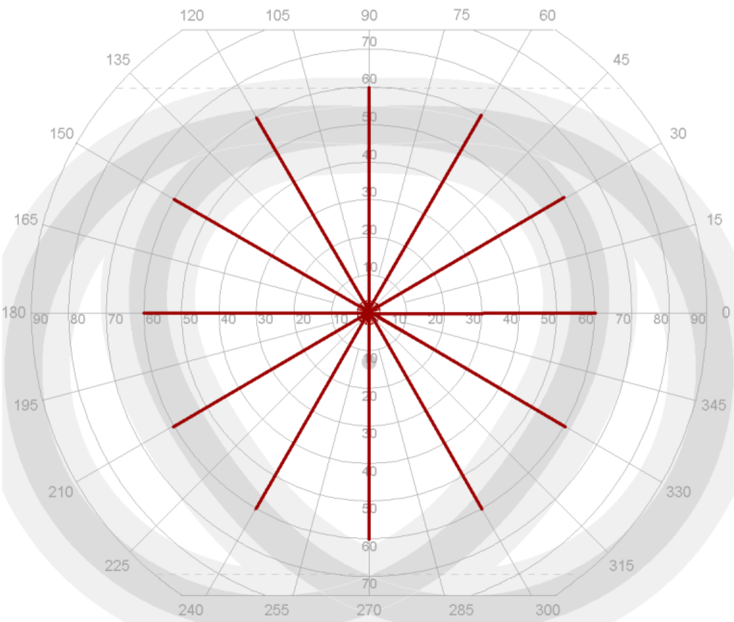


Figure 5.4. The twelve meridians assessed in the binocular kinetic assessment. Vectors were spaced every 30 degrees, and were presented from 60 degrees.

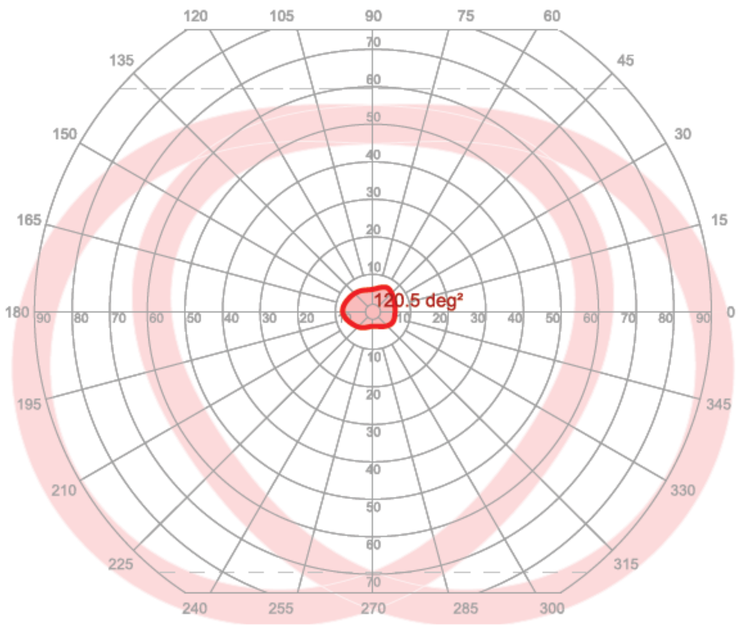


Figure 5.5 Binocular kinetic visual field results of participant 12. The automatically calculated solid angle (120.5 deg^2) is shown. The extent of the field was also determined manually (5.5 deg in this instance) to derive an average field extent.

The two tests conducted on the HFA were as follows:

4. Monocular threshold

   The central 24-2 threshold test was used to assess monocular visual fields. The SITA-Fast strategy was utilised. The central 24-2 assesses the function of approximately the central 24 degrees around fixation and up to 30 degrees nasally from fixation with 54 test points located 6 degrees apart (Figure 5.6). Full aperture trial lenses were used in adult half eye trial frames with lens centration distances corrected for near.

Integrated visual fields scores were manually calculated using the best location algorithm (Crabb et al., 1998; Jampel et al., 2000; Nelson-Quigg et al., 2000; Crabb & Viswanathan, 2004; Aspinall et al., 2008; Chisholm et al., 2008; Asaoka et al., 2011; Saunders et al., 2012; Crabb et al., 2013), and provided an existing assessment against which the custom test designs could be assessed. The mean threshold of each point in the right visual field was compared to the threshold value of the corresponding point in the left visual field (Figure 5.7). The more sensitive of the two visual field locations for the 52 test points (excluding two nasal points to provide a symmetrical representation of the binocular visual field) were used to calculate the mean threshold of best location points.

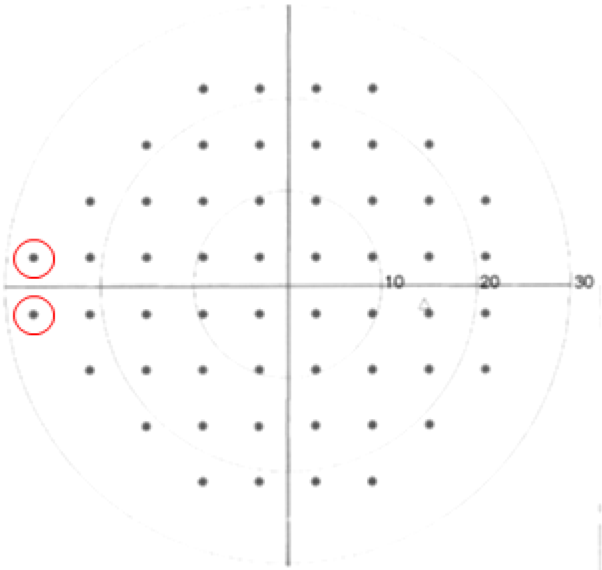


Figure 5.6 The test point pattern for the central 24-2 assessment of the right eye. 54 test points are spaced 6 degrees apart. To provide a symmetrical representation of the binocular visual field, the two circled nasal points were excluded.

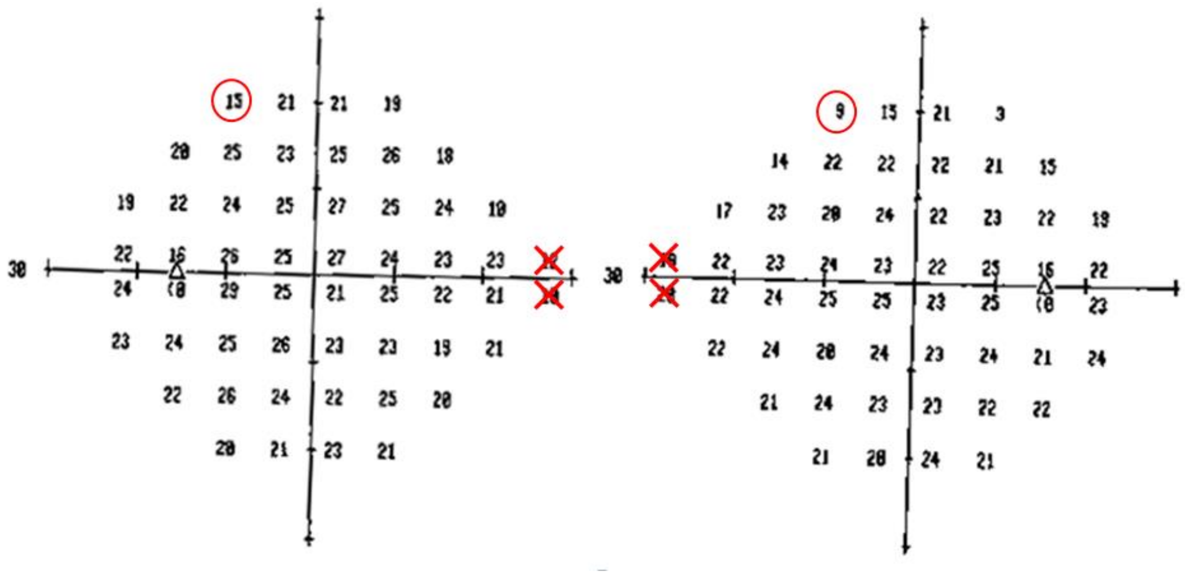


Figure 5.7 Example field results demonstrating how the integrated visual field score was manually derived. The more sensitive of two corresponding visual field locations for the 52 test points was used to calculate the mean threshold of best location points (i.e. for the circles locations, threshold was taken as 15dB). The average of these best location points is the integrated visual field score.

5. Esterman

The binocular Esterman visual field test examines 0-80 degrees with 120 test points (Figure 5.8). Stimuli are presented at each location with a Goldmann size III white stimulus at intensity of 10dB. Missed points are retested and a second negative response is recorded as a defect. The chin rest was positioned as far right as possible and the left hand side of the chin rest was used. This assessment was completed without correction to minimise the possibility of lens and frame artefacts. The number of points seen was used to calculate the percentage Esterman Efficiency score. The Esterman is the only widely available binocular functional field assessment, and provided a further test against which the custom tests can be compared.

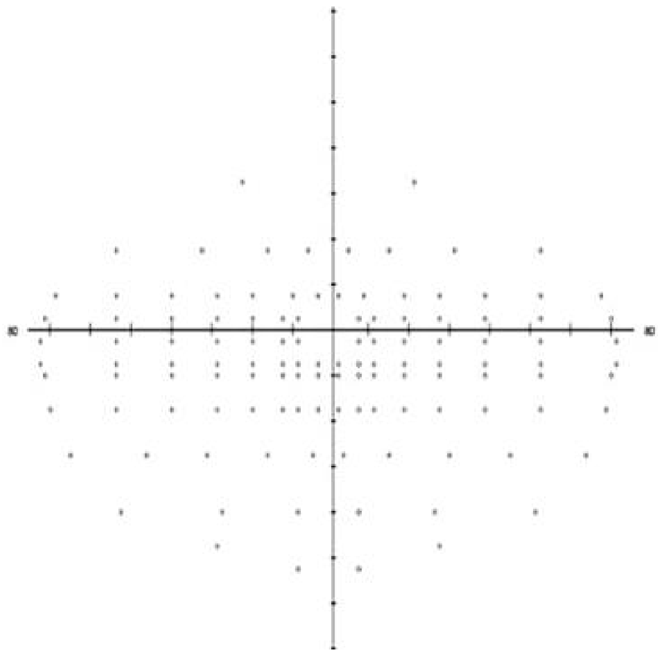


Figure 5.8. Test pattern for the binocular Esterman visual field assessment. The percentage of points seen out of a total of 120 was used in subsequent analyses.

Further qualitative parameters of acceptability of the visual field assessments to participants, and visual field test durations are discussed in Chapter 8.

5.2.5 The Dutch Activity Inventory

The Dutch ICF Activity Inventory (Chapter 2) was again used to reflect overall difficulty with activities of daily living. Responses to the four goals of the mobility domain (mobility at home, mobility indoors in unfamiliar surroundings, mobility outdoors, and using public transport) were used to determine a separate measure of self-reported mobility function.

5.2.6 Independent Mobility Questionnaire

The Independent Mobility Questionnaire (IMQ) Instrument (Turano et al., 1999; Turano et al., 2002) discussed in Chapter 2 was used as a measure of self-perceived ability in mobility. The original instrument comprises two parts: 35 items of mobility situations (part 1), and a series of questions requiring binary responses including questions regarding mobility related behaviour, fall history, and history of mobility training (part 2). Only the first part of the instrument was utilised in the current study.

Participants were asked to rate the level the difficulty they experienced in each of the 35 mobility tasks on a scale of 1 to 5, where 1 denotes no difficulty, and 5 extreme difficulty. Participants were instructed to grade the difficulty experienced completing tasks independently of another person, but with the help of mobility aids if required. This is consistent with the D-AI instructions where participants are asked to grading difficulty of tasks completed without assistance but with low vision and mobility aids if they are used (Bruijning et al., 2010). This is contrary to the intended method of administration of the instrument however, which involves marking tasks completed with any form of assistance as 'not applicable' and omitting these responses from further analyses. This enabled a collection of data from participants with a wider range of visual ability. A further modification involved asking participants to report if they encountered difficulty in each situation to obtain a binary response (Yes/No) before grading the difficulty. For example one item in the instrument is “How difficult is it for you to walk up steps?” Before answering this question the participant was asked “Is it difficult for you to walk up steps?” This protocol was followed for all 35 tasks and enabled the determination of the visual field’s ability to discriminate subjects on the basis of their perceived mobility function using a receiver operating characteristic (ROC) analysis.

5.2.7 Statistical analysis

Questionnaire data were analysed as outlined in Experiment 1 to derive interval results from the ordinal data. Statistical analyses described in Chapter 3 including bivariate correlations, stepwise multiple regressions, and ROC analyses used to explore the demographic, visual field, and other clinical visual function variables, and to investigate the relationship between the predictor variables and self-reported function.

For multiple regressions, Cook’s distance and Mahalanobis’ distances were again reviewed to determine if any an outlying case exerted undue influence on the regression model (Field, 2005). Unless specified otherwise, no case in any of the multiple regression models had a Cook’s Distance of >1, suggesting none had an undue influence on the regression models. Unless otherwise indicated, the Durbin-Watson statistic was close to 2 for the analyses, supporting the presence of independent errors.

The fit of each regression model to the data were assessed by reviewing the residuals. For all our regression models unless indicated otherwise, residuals were not significantly different from normal, and exploration of the standardised residual against standardised predicted value plots supported the assumptions of homoscedasticity and linearity. The probability plots of regression standardised residuals also indicate a normal distribution.

5.3 Results

5.3.1 Descriptive statistics

Table 5.1 illustrates the descriptive statistics for the demographic variables of the fifty participants. Since 72% of sample were returning participants from the first experiment, the univariate analysis reflects results discussed in Chapter 3. The typical participant was a middle aged male. For the majority of the sample, the ocular diagnosis refers to the main cause of visual impairment as reported by the participant since previous sight test records were not available for all participants. The most common reported primary causes were glaucoma (46%), and RP (28%). The majority of participants reported living with family (66%). Participants were mostly retired (54%), although a significant portion were working full or part time (42%). Over a third of the sample were registered severely sight impaired (36%). A similar number reported using low vision aids (30%), and almost half reported using mobility aids (46%).

Demographic variables	
Gender (n)	29 Males, 21 Females
Age (years)	
Median (25% IQ-75% IQ)	64(55-71)
Min-max	24-84
Ocular diagnosis (n)	
RP	14
Glaucoma	23
Retinal detachment	4
Other	9
Duration of visual impairment (years)	
Median (25% IQ-75% IQ)	14(6-29)
Min-max	1-49
Registration status (n)	
Registered severely sight impaired	18
Registered sight impaired	8
Not registered	24
Living arrangements (n)	
Alone	16
With family	33
Warden assisted	1
Current employment status (n)	
Working full time	10
Working part time	11
Student	1
Unemployed	1
Retired	27
Number of prescribed medications (n)	
Median (25% IQ-75% IQ)	3(1-4)
Min-max	0-14
Number of co-morbidities (n)	
Median (25% IQ-75% IQ)	2(1-3)
Min-max	0-6
Use of mobility aids (n)	
White cane or guide dog	23
No mobility aids used	27
Use of low vision aids (n)	
Yes	15
No	35
How many falls have you had in the past 12months? (n)	
Median (25% IQ-75% IQ)	1(0-2)
Min-max	0-30

Table 5.1 Descriptive statistics for the demographic variables.

5.3.1.1 Clinical function variables

Table 5.2 provides descriptive statistics of the clinical visual function assessments (n=50). Function values are similar to those obtained in Experiment 1, indicating a similar degree and range of function in both participant groups.

	Mean (±std)	**Median (25% IQ-75% IQ))**	**Range**
Binocular VA (LogMAR)	0.28(±0.08)	0.09(-0.06-0.50)	-0.28-3.00
Binocular CS (LogCS)	1.51(±0.07)	1.65(1.30-1.95)	0.00-1.95
Binocular reading acuity (LogMAR)	0.40(±0.10)	0.12(0.01-0.50)	-0.10-3.00
Maximum reading speed (wpm)	137.38(±0.10)	145.64(122.46-166.67)	122.46-166.67
Critical print size (LogMAR)	0.44(±0.05)	0.40(0.20-0.60)	-0.10-1.30

Table 5.2 Descriptive statistics of the clinical visual function assessments (n=50). The mean ± standard deviation, and the median (interquartile range) are given.

5.3.1.2 Visual field assessment outcomes

Descriptive statistics of the visual field scores are provided in Table 5.3.

	Mean (±std)	Median (25% IQ-75% IQ))	Range
Binocular threshold (dB)	10.87(±1.19)	10.14(2.13-19.40)	2.13-19.40
Binocular suprathreshold (%)	54.48(±5.09)	58.53(18.8-93.18)	2.27-98.86
Binocular kinetic solid angle (deg^2)	5966.77(±541.19)	7355.7(1783.80-9566.70)	64.20-10320.50
Esterman (%)	59.43(±4.81)	67.08(33.33-90.83)	0.00-100.00
Integrated monocular threshold (dB)	15.69(±1.52)	15.17(4.88-26.48)	0.90-31.96

Table 5.3 Descriptive statistics of the visual field scores. The mean ± standard deviation, and the median (interquartile range) are given

1		1		0		0		1		0	
4	7.5	8.5	8.5	2	2	4	0	2	7.5	2.5	3
				5	5.5	5.5	6				
6	12.5	6	11.5	6	15	15	14	9	5	9	5.5
		17	14	12	17	21	16	18	15.5		
8	14.5	16	17	15	24	24	19	17	16	14.5	5.5
		9	15.5	18	17	17	18	17	12		
11	12	14	15.5	15.5	17.5	17	19	14.5	14	11	3.5
				13	9.5	14	16				
0		8.5		10.5		8		7.5		0	
		2.5		4		3.5		0			

Figure 5.9 Median scores for each location in the visual field with the binocular threshold assessment. The grey area indicates the central 0-30 degree region of the visual field.

		9	11.5	10.5	11.5		
	13.5	12.5	7.5	18.5	17.5	8.5	
17	15.5	16	18.5	20.5	17.5	16	11
16	15	21.5	25	23.5	23	12.5	20.5
18	18.5	18.5	12	23.5	28	26.5	24
17	23	24.5	22	24.5	23	21	17
	18	18.5	16.5	21	23.5	19	
		19	22	23	19		

Figure 5.10 Median scores for each location in the visual field as given by the integrated visual field assessment.

Table 5.3 shows the average results for each of the usual field paradigms assessed and Figures 5.9 and 5.10 show meridian scores by location for the two threshold assessments, binocular threshold (Figure 5.9) and IVF (Figure 5.10). Kinetic results were considered both by calculating the average field extent, and the solid angle subtended by the isopter obtained.

5.3.2 Kinetic visual fields: average extent vs solid angle

To further investigate methods of quantifying the kinetic field, a further analysis of the kinetic data were undertaken. Similarly to Moenter et al., (2017), the visual field extent along the twelve principal meridians were averaged to give an overall average visual field extent in degrees. Figure 5.11 shows the highly correlated relationship between the kinetic solid angle and the field extent scores. The kinetic average extent is also similarly related to overall and mobility self-reported function when compared with the kinetic solid angle score. Results of these bivariate regressions are provided in Table 5.4, and suggest that either method of quantifying the kinetic field provides a good prediction of perceived function. Solid angle was chosen to represent the kinetic visual field in subsequent analyses presented.

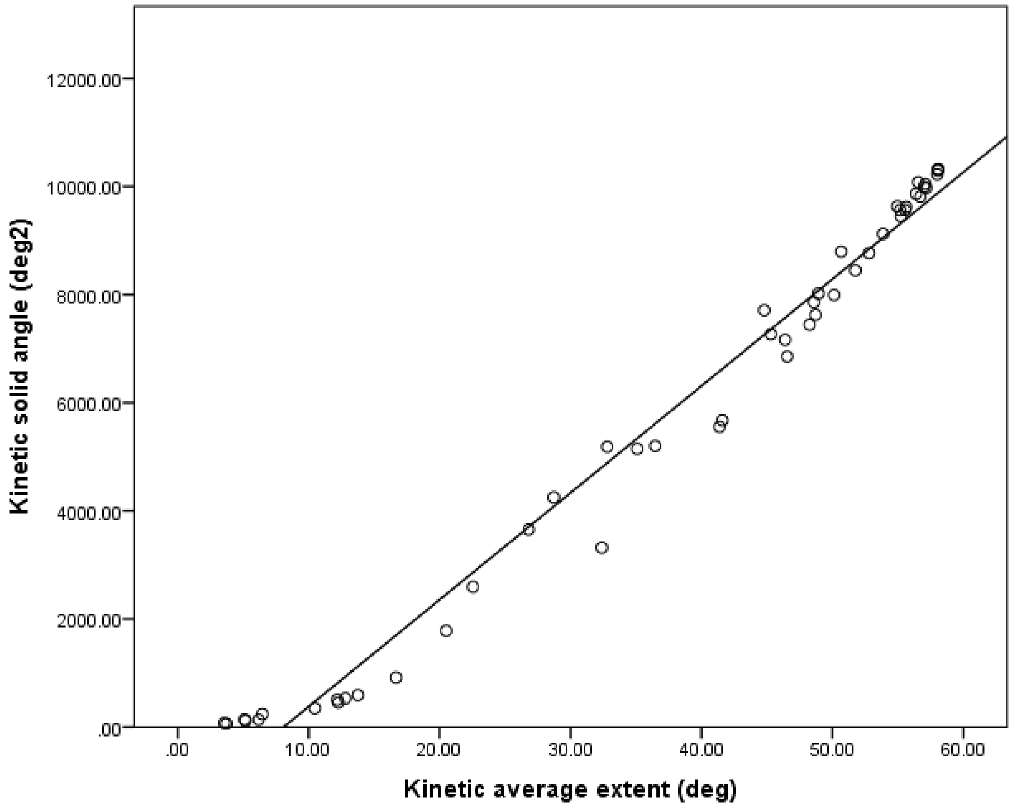


Figure 5.11 Graphical representation of the relationship between the kinetic solid angle, and field extent scores (R^2=0.99, p<0.001).

	Overall D-AI score (R^2)	Mobility function (R^2)
Kinetic solid angle	0.41*	0.48*
Kinetic average field extent	0.39*	0.48*

Table 5.4 Bivariate analysis between overall D-AI and self-reported mobility function and the kinetic field scores. Non parametric 2-tailed Spearman's correlations coefficients are used (*p<0.001).

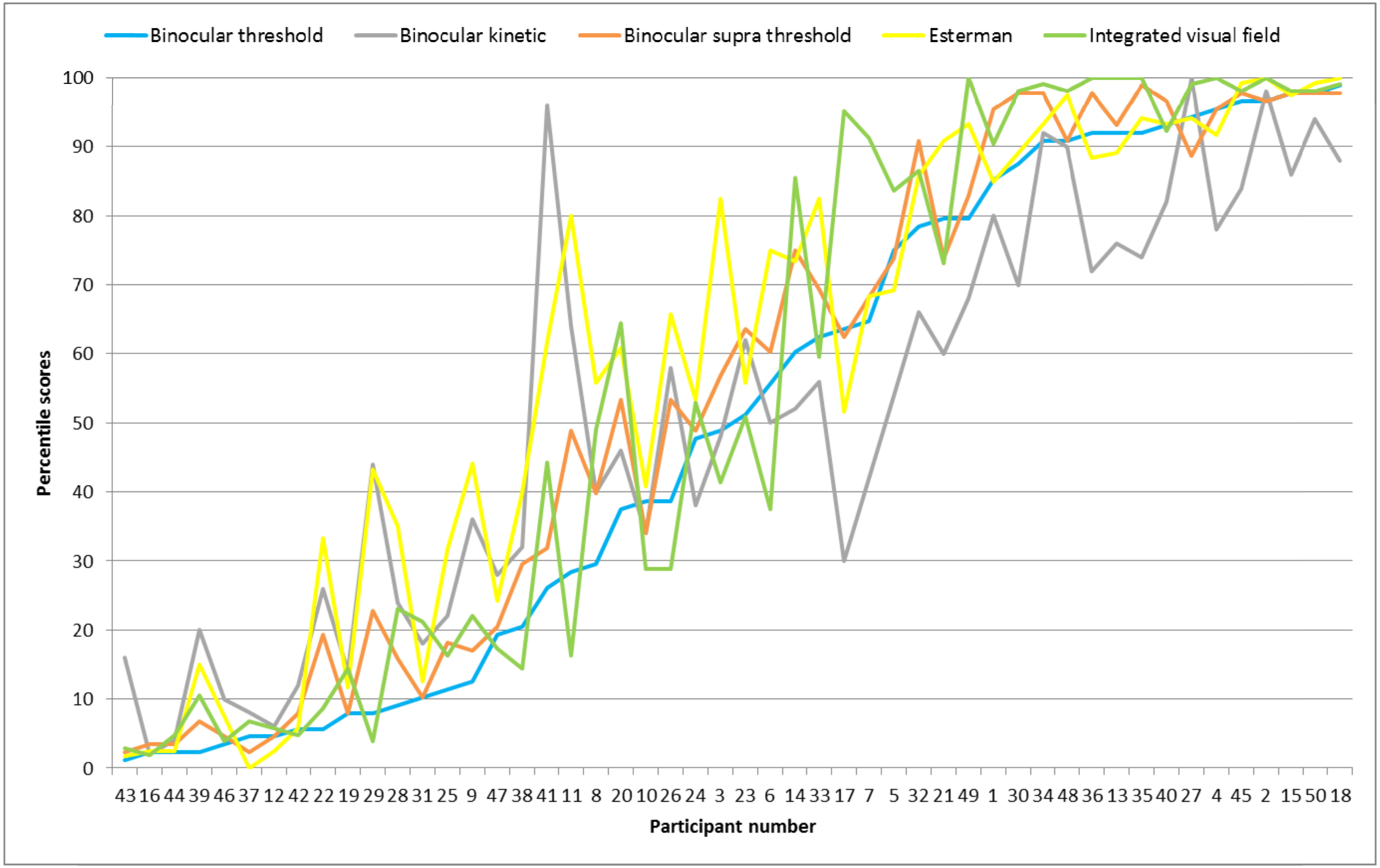


Figure 5.12 Graphical comparison of the 5 visual field scores. Binocular threshold, binocular kinetic, and integrated visual field scores are converted to percentages to allow for comparison with binocular suprathreshold and Esterman scores. x axis is ordered by binocular threshold score, with the lowest score at the left, and the highest to the right of the scale.

Reliability statistics indicate adequate visual field reliability for the majority of our sample (Table 5.5). A cut-off value of 20% was considered to determine acceptable reliability (Newkirk et al., 2006). Fixation losses for the monocular threshold tests suggest reliable results, with only 18% of participants losing fixation more than 20% during both assessments. Although no objective fixation data are available for binocular fields assessments, the fixation reliability of monocular tests provide an indication of reliability of binocular tests. False positives and false negatives in integrated monocular threshold tests were less than 20% for the entire sample (false positives 1.00±1.00, false negatives 4.53±2.13). Binocular threshold data indicate 90% of false positive and false negative statistics were better than 20%. This figure is similar to Esterman results where 86% of the sample had false positives or false negatives less than 20%, and a little greater than suprathreshold results where 78% had false positives or false negatives greater than 20%.

		Mean fixation losses (±std)	**Mean false positives (±std)**	**Mean false negatives (±std)**
Binocular threshold (dB)			2.68(±0.70)	8.48(±1.68)
Binocular suprathreshold (%)			2.36(±1.02)	12.60(3.11)
Binocular kinetic solid angle (deg^2)				
Esterman (%)			3.10(±0.82)	7.16(±1.87)
Integrated monocular threshold (dB)	**RE**	0.08(±0.03)	1.25(±0.41)	3.76(±1.05)
	LE	0.11(±0.03)	0.76(±0.25)	4.53(±1.24)

Table 5.5 Reliability indices for the visual field assessments.

A significant Kolmogorov-Smirnov statistic indicates a non-normal distribution of all visual field scores (binocular threshold 0.135, p=0.023, binocular suprathreshold 0.149, p=0.008, binocular kinetic 0.163, p=0.002, Esterman 0.151, p=0.006, integrated monocular threshold 0.134, p=0.026), and therefore non-parametric statistical tests are used.

5.3.3 Self-reported function

5.3.3.1 Dutch Activity Inventory

Interval data were derived from the ordinal D-AI scale in Rasch analysis. As in Experiment 1, the difficulty of goals was graded by the respondent on a five point scale (1- not difficult, 2- slightly difficult, 3- moderately difficult, 4- very difficult, and 5- impossible without help). Higher derived person measures therefore reflect greater difficulty, or lower ability, and higher item difficulties indicate a reduced ability required to achieve the item, i.e. a 'easier' item.

Person measures were derived from the data set directly, using all 44 items as before. Item difficulties (Appendix 2.3) are consistent with those in Experiment 1. The person separation is 2.62 (Reliability 0.87), indicating that individuals can be reliably ordered by the instrument in terms of their level of perceived ability. Item separation is 2.77 (Reliability 0.88), which is slightly less than the minimum acceptable value of 3 indicating the instrument might not be able to reliably ordered in terms of their difficulty. Targeting is also poor with a mean person measure of -2.30±1.96 logits. The low mean person measure indicates that the current sample has a higher ability, on average, than the questionnaire is aimed at. The difference in the targeting between the sample groups in the two studies was expected since 46% of the current sample reported glaucoma as their primary ocular diagnosis, and demonstrated a greater degree of residual visual field when compared with RP participants.

The fit of the items was next considered, as an initial representation of how well the questions fitted a unidimensional construct. There were five mis-fitting items with fits in the range between 1.5-2.0 and a further two with fits greater than 2.0 (outfits of 2.69 and 2.34). Item parameters of the 44 goals as determined by Rasch analysis are provided in Appendix 2.3.

It was considered important to keep the outcome measure also needs to be comparable with Experiment 1 of this thesis, and with broader populations of low vision patients with a range of visual difficulties. It was therefore considered that keeping the range of activities of daily living included in the questionnaire as broad as possible was important. The D-AI was used as the main outcome measure representing overall activity limitation in the analyses below.

Person measures were derived by Rasch analysis for the mobility domain. Person separation was 1.87 (Reliability 0.78), and item separation was 2.91 (Reliability 0.89), with all items fitting in the range 0.5-1.5 mean square. Similarly to the previous analyses, targeting is poor (+2.40±2.40 logits).

5.3.3.2 Independent Mobility Questionnaire

Interval data were derived from the ordinal scale for the Independent Mobility Self-Assessment instrument using Rasch analysis (Table 5.6). Person measures were derived from the data set directly, using all 35 items found to be consistent with a unidimensional scale in people with peripheral field loss due to RP (Turano et al., 1999). The person separation is 3.43 (Reliability 0.92), indicating that individuals can be reliably ordered by the instrument in terms of their level of perceived ability. Item separation is 2.95 (Reliability 0.90), which is very slightly less than the minimum acceptable value of 3 indicating the instrument might not be able to reliably order items in terms of their difficulty. Targeting (-1.23, ±1.64 logits) is close to the favourable range of within ±1 logits of the mean item difficulty (Latham et al., 2015a).

The fit of the items was next considered, as an initial representation of how well the questions fitted a unidimensional construct. There were three mis-fitting items with fits in the range between 1.5 and 2.0. This is comparable to the original Rasch analysis of the instrument in a sample of 127 patients with RP (Turano et al., 1999), and the subsequent validation in a sample of 83 patients with glaucoma (Turano et al., 2002) where three items were mis-fitting within this range in both studies. A further study validated the questionnaire in a small sample (n=30) of mixed low vision patients (Bibby et al., 2007) and found one outfitting item between 1.5 and 2.0, and a further two with outfits of greater than 2. Fenwick et al., (2016) explored the IMQ's psychometric properties in 40 participants with advanced RP and found three mis-fitting items between 1.5 and 2.0. The fits in the present data can be considered acceptable and do not diminish the validity of the measures, and so all items are considered to contribute to the analysis.

Goal	Item difficulty	SE	Infit mnsq	Oufit mnsq	Applic-ability
Walking at night	-1.60	0.18	1.11	0.98	46
Walking in high-glare areas	-1.38	0.17	1.27	1.39	50
Adjusting to lighting changes at night: Indoor to streetlights	-1.04	0.17	0.89	0.86	50
Avoiding bumping into: Head-height objects	-0.99	0.17	0.89	0.89	50
Moving about in crowded situations	-0.87	0.18	0.87	0.79	46
Walking in dimly lit indoor areas	-0.82	0.17	1.36	1.28	50
Avoiding tripping over uneven travel surfaces	-0.79	0.17	0.86	0.86	50
Adjusting to lighting changes during the day: Outdoor to indoor	-0.73	0.17	1.12	1.07	50
Adjusting to lighting changes during the day: Indoor to outdoor	-0.56	0.17	1.02	0.98	50
Avoiding bumping into: People	-0.47	0.17	0.76	0.67	50
Detecting descending stairwells	-0.46	0.18	1.2	1.09	46
Walking in unfamiliar areas	-0.43	0.18	0.65	0.6	46

Seeing cars at intersections	-0.35	0.17	1.22	1.14	50
Being aware of another person's presence	-0.32	0.17	0.79	0.65	50
Moving around in social gatherings	-0.26	0.17	0.56	0.56	50
Avoiding bumping into: Knee-height objects	-0.29	0.17	1.17	1.03	50
Avoiding bumping into: Low-lying objects	-0.26	0.17	1.1	0.97	50
Walking down steps	-0.17	0.17	1.51	1.63	50
Adjusting to lighting changes at night: Streetlights to indoor	-0.14	0.17	1.14	1.36	50
Avoiding bumping into: Shoulder-height objects	-0.02	0.18	1.01	0.86	50
Finding restrooms in public places	0.11	0.18	1.24	0.96	50
Moving about in stores	0.17	0.19	0.76	0.6	46
Stepping off curbs	0.27	0.18	0.91	1.23	50
Stepping onto curbs	0.41	0.18	1.09	1.32	50
Detecting ascending stairwells	0.57	0.2	1.04	0.94	46
Avoiding bumping into: Waist-height objects	0.58	0.19	1.25	0.91	50
Using public transport	0.67	0.21	1.51	1.75	44
Avoiding bumping into: Walls	0.73	0.19	0.81	1.03	50
Walking through doorways	0.77	0.2	0.79	0.56	50
Moving about in the classroom	0.80	1.03	0	0	1
Moving about in outdoors	0.81	0.2	1.19	0.82	46
Walking up steps	0.92	0.2	1.38	1.76	50
Moving about in the home	1.58	0.24	1.17	0.65	46
Walking in familiar areas	1.64	0.25	0.91	0.6	46
Moving about at work	1.94	0.4	0.72	0.43	26

Table 5.6 Item parameters of the 35 mobility tasks of the IMQ as determined by Rasch analysis. Tasks are ordered by item difficulty, with the most difficult item first. Infit and oufit mnsq values, indicating the fit of the item to the underlying unidimensional construct are given. Applicability indicates the number of participants (max n=50) to whom the item was important or applicable

5.3.4 Domain 4 vs IMQ

Responses to the four tasks under the mobility domain (as used to represent mobility in Experiment 1) were also analysed separately and compared to the results of the IMQ. Both measures of self-reported function are significantly correlated (R^2=0.71, p<0.001) (Figure 5.13).

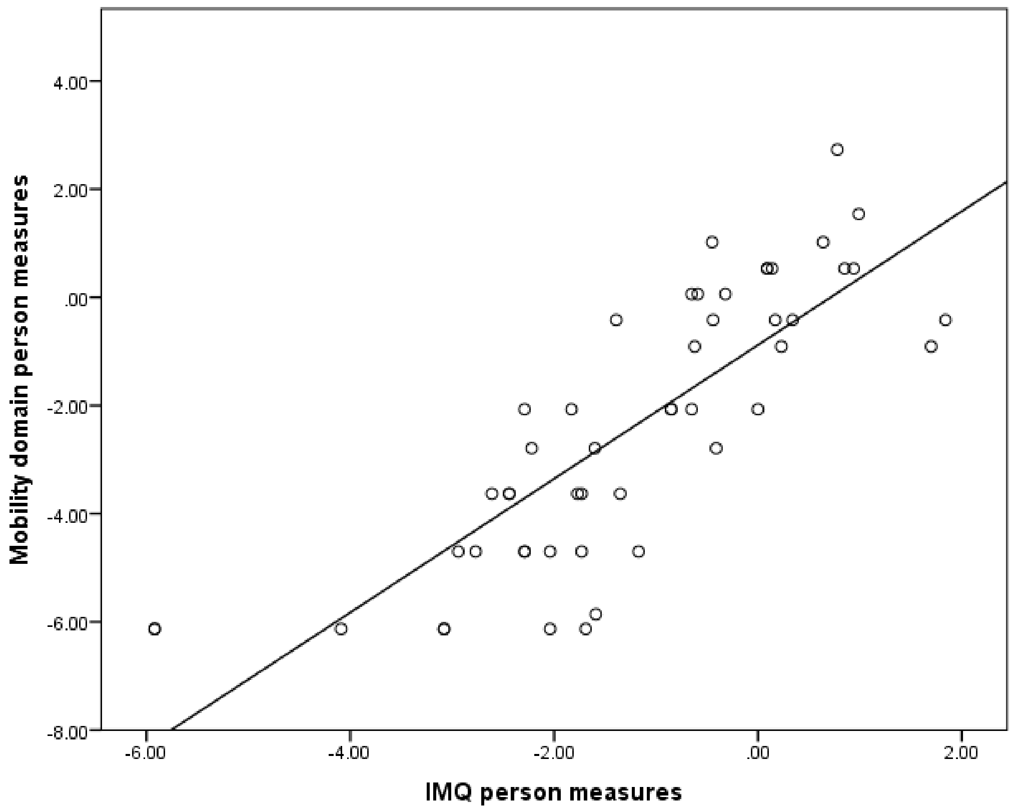


Figure 5.13. Graphical representation of the relationship between IMQ person measure, and mobility domain person measures (R^2=0.71, p<0.001).

Comparing the mobility domain of the D-AI (4 questions) and the IMQ (35 questions) the person separation in Rasch analysis suggests that the respondents are more reliably ordered by the IMQ (3.43 (reliability 0.92)), than by the mobility domain of the D-AI (1.87 (reliability 0.78)). Targeting is also closer to the favourable range (within ±1 logits of the mean item difficulty (Latham et al., 2015a) for the IMQ (-1.23 logits, ±1.64) compared with the mobility domain (+2.40 logits, ±2.40 logits). Item separation is similar for the IMQ (2.95 (reliability 0.09)) and mobility domain of the D-AI (2.91 (reliability 0.89)). Person measures for the IMQ constitute a more reliable scale and are considered to represent mobility function more accurately than responses to the four tasks underpinning the mobility domain in the D-AI. For this reason, and also since the IMQ consists of more individual tasks for consideration in ROC analysis, it is used to represent self-reported mobility function in the remaining analyses.

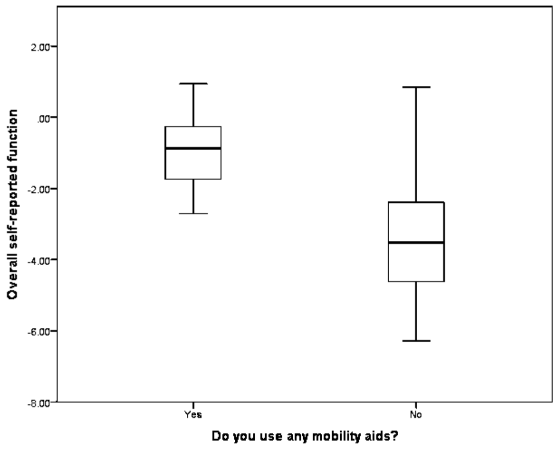
5.3.5 Relationship between self-reported function and the predictor variables

5.3.5.1 Demographic

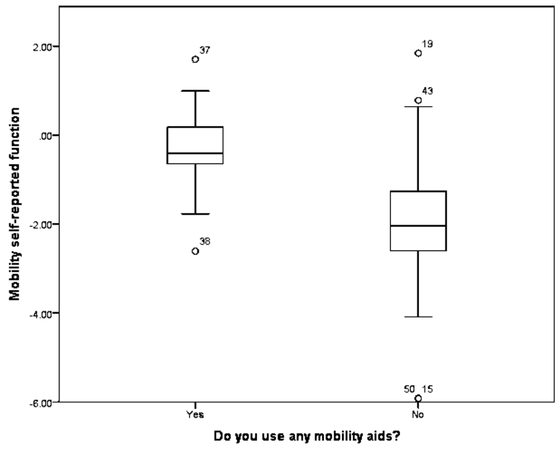
The relationships between the demographic and clinical function variables and self-reported overall and mobility function are provided in Table 5.7.

Demographic variables	Overall D-AI score	IMQ score
Dichotomous variables (U)		
Gender	U=-1.504	U=-0.727
Use of mobility aids	U=-4.260*	U=-3.690*
Use of low vision aids	U=-3.673*	U=-2.901*
Nominal variables (χ^2)		
Ocular diagnosis	χ^2= 10.350	χ^2= 11.032
Living arrangements	χ^2= 0.933	χ^2= 1.426
Current employment status	χ^2= 4.871	χ^2= 3.846
Ordinal and continuous variables (R^2)		
Sight loss registration	R^2=0.43*	R^2=0.47*
Age	R^2=0.02	R^2=0.05
Duration of visual impairment	R^2=0.30*	R^2=0.25*
No of medications	R^2=0.00	R^2=0.06
No of comorbidities	R^2=0.00	R^2=0.09
Number of falls in the past 12 months	R^2=0.00	R^2=0.00

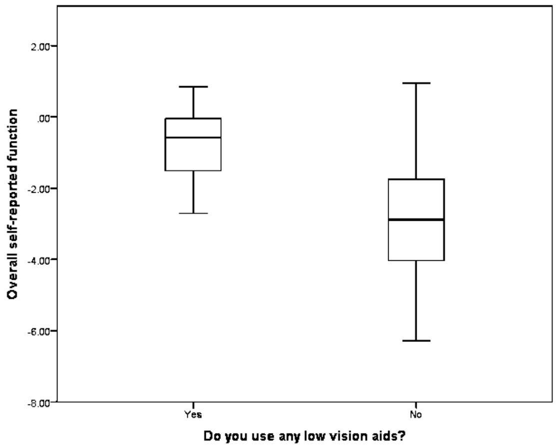
Table 5.7 Relationship between the variables assessed, and self-reported overall and mobility function. Mann-Whitney U tests were conducted for the dichotomous predictors, Kruskal-Wallis tests were performed on the nominal variables, and the continuous and ordinal variables were compared to self-reported function in 2-tailed Spearman's rho bivariate correlations (*p<0.004, for all others p≥0.004).



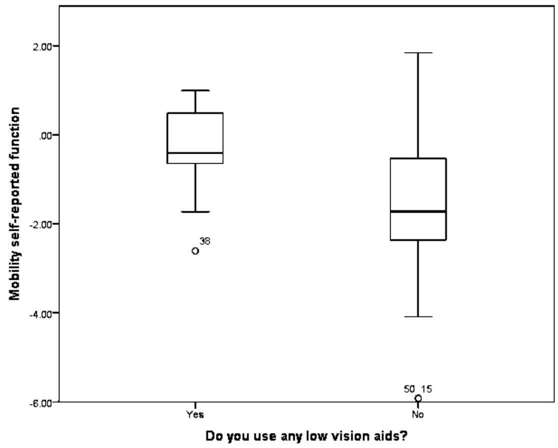
Overall self-reported function
2.00
.00
-2.00
-4.00
-6.00
-8.00
Yes
No
Do you use any mobility aids?



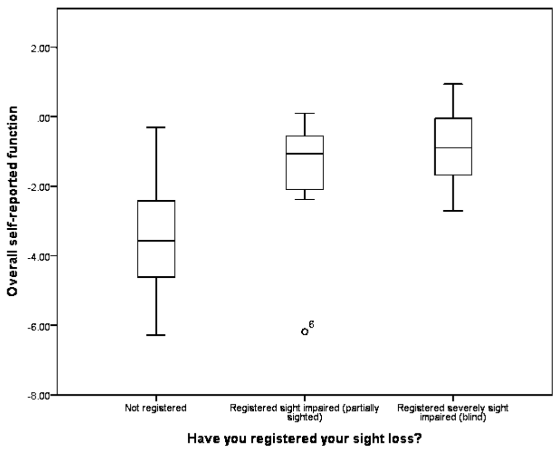
Mobility self-reported function
2.00
.00
-2.00
-4.00
-6.00
37
38
19
43
50 15
Yes
No
Do you use any mobility aids?



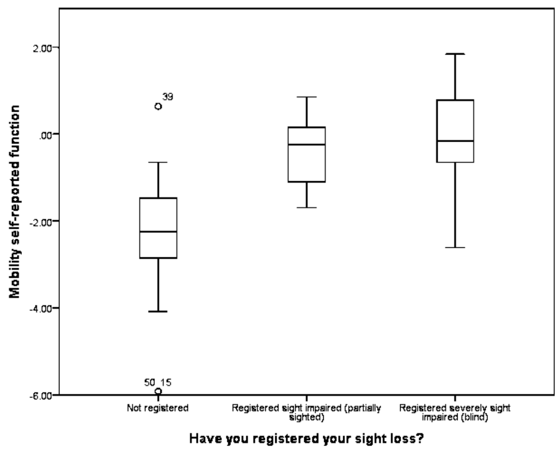
Overall self-reported function
2.00
.00
-2.00
-4.00
-6.00
-8.00
Yes
No
Do you use any low vision aids?



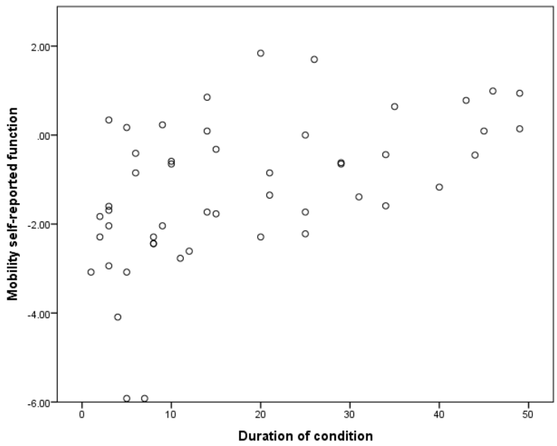
Mobility self-reported function
2.00
.00
-2.00
-4.00
-6.00
38
50 15
Yes
No
Do you use any low vision aids?



Overall self-reported function
2.00
.00
-2.00
-4.00
-6.00
-8.00
6
Not registered
Registered sight impaired (partially sighted)
Registered severely sight impaired (blind)
Have you registered your sight loss?



Mobility self-reported function
2.00
.00
-2.00
-4.00
-6.00
39
50 15
Not registered
Registered sight impaired (partially sighted)
Registered severely sight impaired (blind)
Have you registered your sight loss?



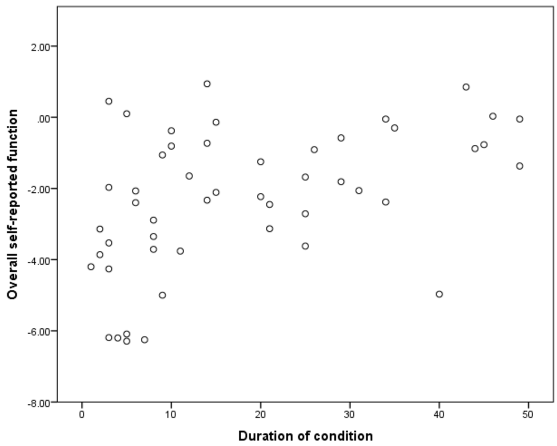


Figure 5.14 Graphical representations of the significant relationships between demographic variables and overall self-reported function.

In comparing the demographic variables with overall and mobility function, due to the multiple number of comparisons performed (12) a more stringent significance level is more appropriate for these tests, as suggested by the Bonferroni correction (Field, 2005). A corrected significance level of p=0.004 was used

Mann-Whitney U tests were conducted for the dichotomous predictors to establish whether the means of the independent samples significantly differed. Self-reported function was significantly more difficult for individuals who reported using mobility aids than for those who did not for both overall (Mann-Whitney U=-4.26, p<0.001) and mobility related function (Mann-Whitney U=-3.69, p<0.001). Similarly, participants using low vision aids reported greater difficulty overall (Mann-Whitney U=-3.67, p<0.001) and with mobility related tasks (Mann-Whitney U=-2.90, p<0.001).

Kruskal-Wallis tests were performed on the nominal variables as a non-parametric determination of differences between the independent groups. None of these variables significantly related to overall and mobility related self-reported function.

The ordinal and continuous demographic variables were compared to D-AI scores in 2-tailed Spearman's rho bivariate correlations. As Table 5.7 and Figure 5.14 indicate, sight loss registration significantly related to overall self-reported function (R^2=0.43, p<0.001) and mobility related function (R^2=0.47, p<0.001), where participants registered as severely sight impaired reported worse function. A similar relationship was found between the duration of visual impairment and self-reported function. Participants with longstanding visual impairments reported greater overall (R^2=0.30, p<0.001) and mobility related (R^2=0.25, p<0.001) difficulty.

5.3.5.2 Clinical function

Clinical measures of visual function were compared to self-reported function in bivariate analyses. A Bonferroni corrected significance level of p=0.01 was used.

	Overall D-AI score (R^2)	**Mobility function (R^2)**
Binocular VA (LogMAR)	0.43*	0.31*
Binocular CS (LogCS)	0.52*	0.33*
Binocular reading acuity (LogMAR)	0.43*	0.30*
Critical print size (LogMAR)	0.24*	0.19*
Maximum reading speed (wpm)	0.28*	0.29*

Table 5.8 Bivariate analysis between overall D-AI and self-reported mobility function and the clinical visual function variables. Non parametric 2-tailed Spearman's correlations coefficients are used (*p<0.01).

Table 5.8 and Figure 5.15 illustrate the results of bivariate analyses for clinical visual function. All clinical visual function variables correlate significantly ($p<0.01$) with overall self-reported visual function, with the most significant relationship found between overall self-reported function and binocular CS ($R^2=0.52$, $p<0.001$). Perceived mobility function correlated similarly with binocular VA ($R^2=0.31$, $p<0.001$) and binocular CS ($R^2=0.33$, $p<0.001$).

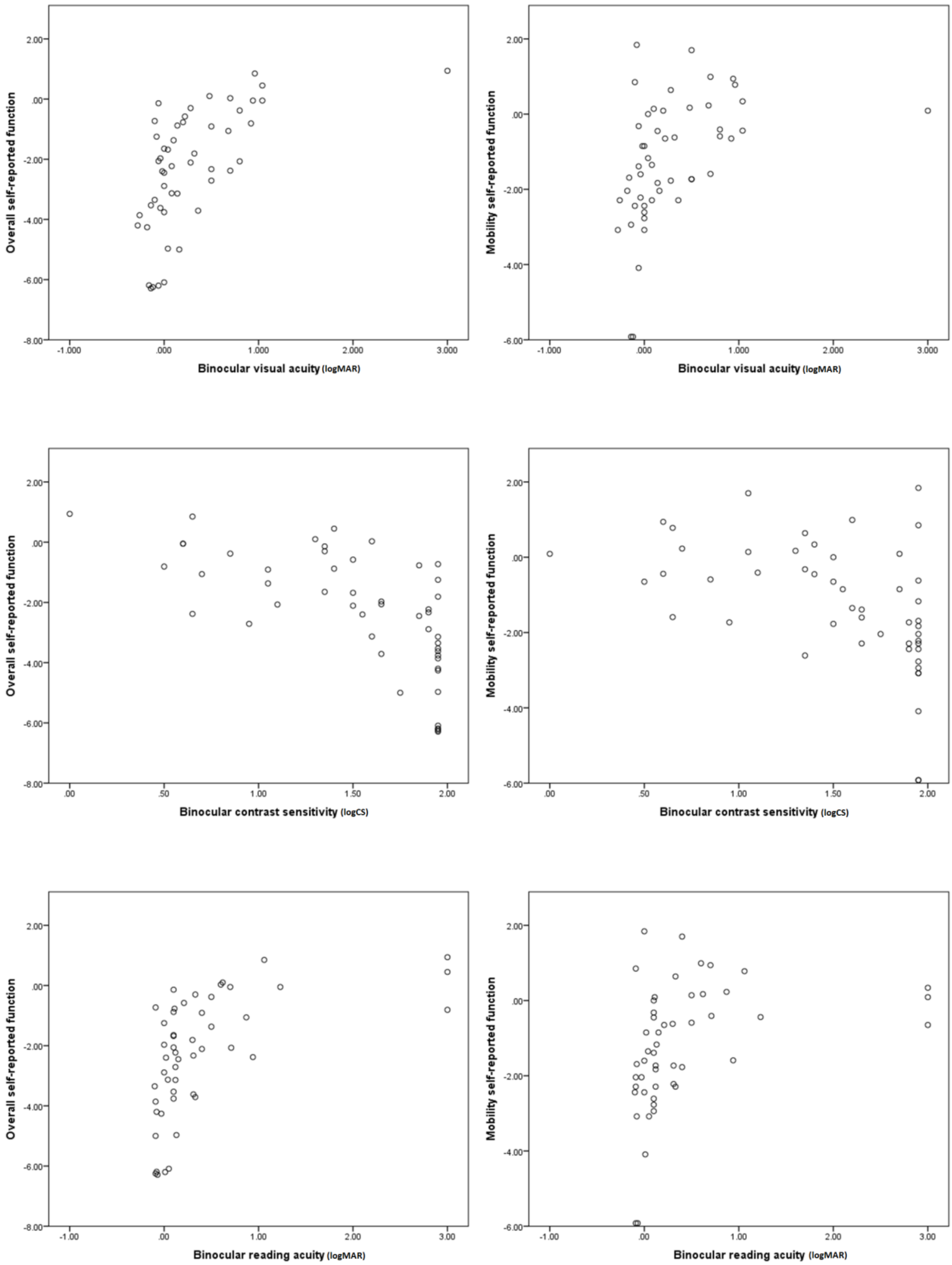


Figure 5.15 Graphical representations of the relationship between clinical function variables and overall and mobility self-reported function in logits.

5.3.5.3 Visual field

A series of graphs comparing the relationship between the five visual field scores is provided in Figure 5.16.

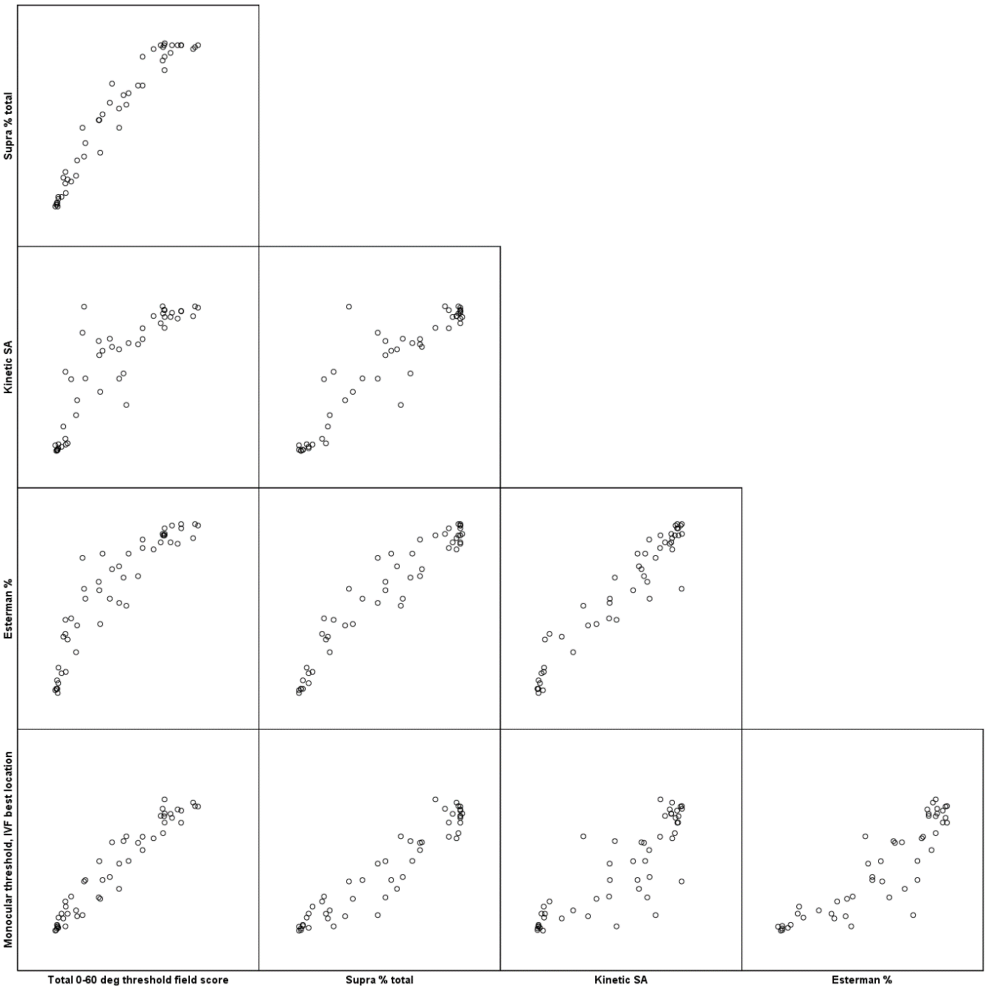


Figure 5.16 Comparison of the relationship between the five visual field scores.

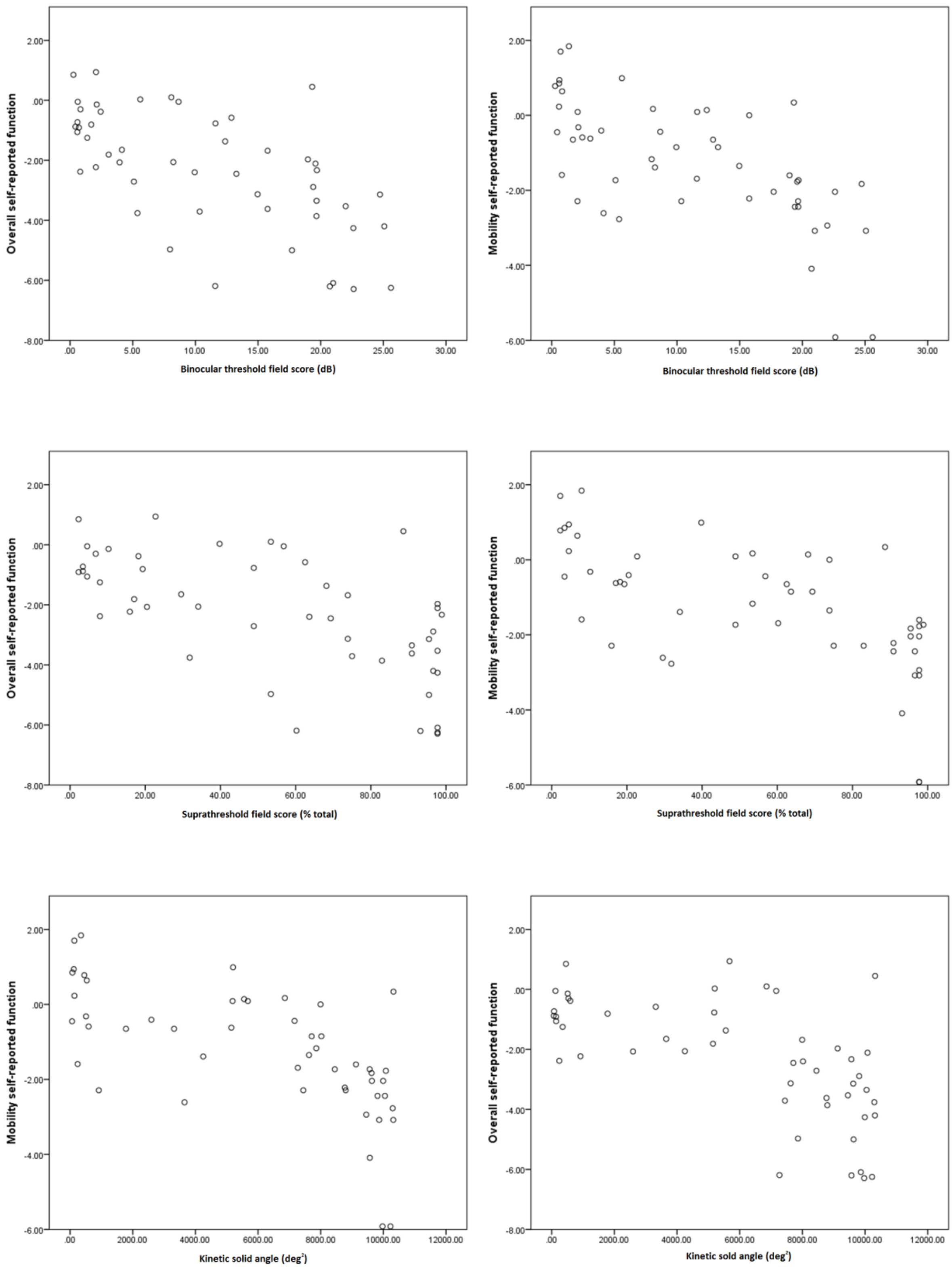
	Binocular threshold	Binocular suprathreshold	Binocular kinetic	Esterman	IVF
Binocular threshold					
Binocular suprathreshold	R^2=0.93*				
Binocular kinetic	R^2=0.78*	R^2=0.79*			
Esterman	R^2=0.90*	R^2=0.90*	R^2=0.88*		
IVF	R^2=0.92*	R^2=0.86*	R^2=0.72*	R^2=0.82*	

Table 5.9 Spearman rho correlation matrix showing the relationship between the visual field scores (*p<0.001).

There is a strong correlation (R^2=0.81, p<0.001) between all five visual field scores (Figure 5.16, Table 5.9). The strongest relationship is between the threshold and suprathreshold assessments (R^2=0.93, p<0.001). Both these tests assessed the visual field binocularly out to 60 degrees, and utilised the same 88 point test pattern. The binocular threshold and IVF assessments were also highly correlated (R^2=0.93, p<0.001). The suprathreshold and Esterman tests assessed the binocular field using the same paradigm, and were also highly correlated (R^2=0.90, p<0.001). Further investigation indicated that these strong relationships were likely to adversely affect the results in subsequent regression analyses due to multicollinearity if entered into the same regression. The variance inflation factors and tolerance statistics indicated the presence of significant multicollinearity between threshold and suprathreshold scores (15.66), and threshold and IVF scores (14.68) (Field, 2005). The tolerance statistics were also less than 0.1 (Menard 1995, O'Brien, 2007) for these variable associations (0.06 for threshold and suprathreshold, and 0.07 for threshold and IVF scores) confirming the presence of a multicollinearity bias. In an attempt to reduce the high VIFs produced by multicollinearity, the predictor variables were standardised by subtracting the mean from each value and then dividing by the standard deviation (Frost, 2017). The multiple regression was then repeated with these standardised predictors. These predictors produced identical collinearity statistics. Multiple regressions with more than one visual field variable included were omitted from the analysis since the models do not satisfy residual assumptions.

	Overall D-AI score (R^2)	**Mobility function (R^2)**
Binocular threshold (dB)	0.42*	0.47*
Binocular suprathreshold (%)	0.40*	0.47*
Binocular kinetic solid angle (deg^2)	0.41*	0.48*
Esterman (%)	0.40*	0.46*
Integrated monocular threshold (dB)	0.32*	0.38*

Table 5.10 Bivariate analysis between overall D-AI and self-reported mobility function and the visual field variables. Non parametric 2-tailed Spearman's correlations coefficients are used (*p<0.001).



Overall self-reported function
2.00
.00
-2.00
-4.00
-6.00
-8.00
.00
5.00
10.00
15.00
20.00
25.00
30.00
Binocular threshold field score (dB)
Mobility self-reported function
2.00
.00
-2.00
-4.00
-6.00
.00
5.00
10.00
15.00
20.00
25.00
30.00
Binocular threshold field score (dB)
Overall self-reported function
.00
20.00
40.00
60.00
80.00
100.00
Suprathreshold field score (% total)
Mobility self-reported function
Suprathreshold field score (% total)
Mobility self-reported function
.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
Kinetic solid angle (deg²)
Overall self-reported function
Kinetic sold angle (deg²)

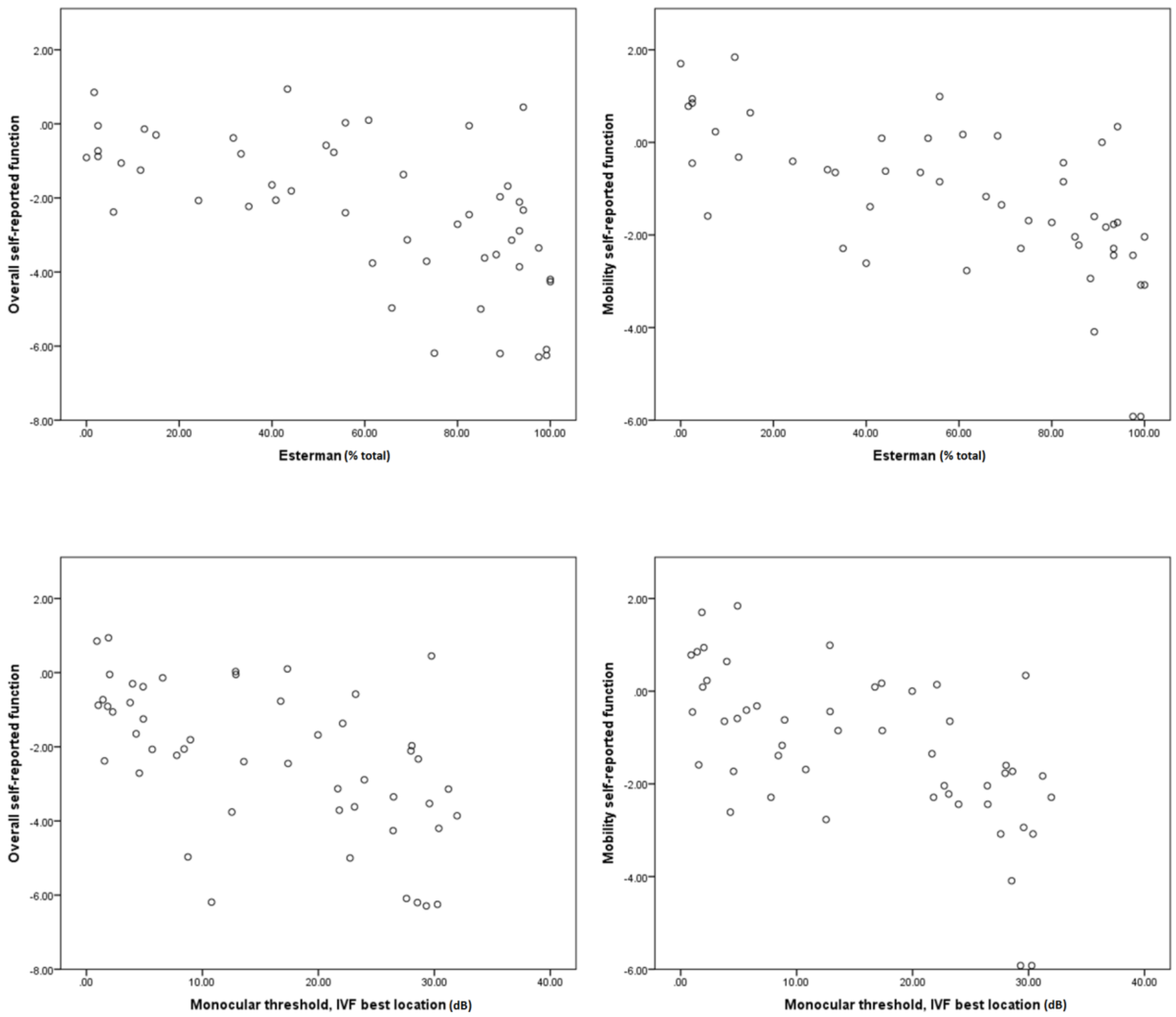


Figure 5.17 Graphical representations of the relationship between visual field variables and self-reported function.

Greater visual field loss is associated with greater self-reported difficulty regardless of the method of field assessment. All visual field paradigms are similarly and significantly related to both overall (R^2=0.32-0.42) and mobility related (R^2=0.38-0.48) self-reported function (Table 5.10, Figure 5.17).

5.3.6 Multiple regression analysis

Clinical function variables previously identified as significantly associated with perceived overall and mobility function were entered into multiple regression analyses, each with a different visual field variable, to try and determine the significant clinical predictors of self-reported function. Binocular VA was entered in multiple regressions, along with binocular CS, and a visual field variable. The results of these analyses are provided in Table 5.11.

Binocular threshold field score was entered in to the first multiple regression analyses. Binocular threshold field score was found to account for 39% of overall self-reported function. This increased to 53% with binocular VA. The primary predictor of perceived mobility function was binocular threshold field score, accounting for 44% of the variation in the results, and 48% when combined with binocular VA.

In the second multiple regression, binocular VA and binocular suprathreshold score accounted for 39% and a further 15% of variance in overall self-reported function respectively. Binocular suprathreshold score was found to explain 41% of variance in self-reported mobility function. This increased to 48% when combined with binocular VA.

Binocular kinetic score accounted for 41% of variance in overall self-reported function. A further 16% could be explained by binocular VA. The binocular kinetic field score was selected as the primary predictor of mobility function explaining 41% of variance in results, and 49% when combined with binocular VA.

The Esterman field score was entered into the fourth multiple regression, and was selected as the primary predictor of self-reported mobility function, accounting for 42% of variance in results. This increased to 49% when combined with binocular VA. Binocular VA explained

39% of overall self-reported function. Esterman field score accounted for a further 16% to this model.

In the final multiple regression analysis, the IVF score was entered. Binocular VA was found to explain 39% of variance in overall perceived function, and 47% when combined with IVF score. IVF score was found to account for 36% of variance in perceived mobility function, and binocular VA accounted for an addition 8%.

In each model the visual field variable was selected as the most significant predictor of self-reported mobility function, accounting for between 36% and 45% of the variance in the results regardless of the method of field analysis. For overall function, either the visual field variable or binocular VA was the primary predictor. Binocular VA was a significant predictor of overall and mobility related function in every model.

a. Binocular threshold	**B**	**SE B**	**β**	**R^2 change**	**95% confidence interval**	
Overall D-AI score					**Lower bound**	**Upper bound**
Constant	-1.78	0.43			-0.16	2.40
Binocular threshold field score	-0.10	0.03	-0.42**	0.39***	-2.59	-0.63
Binocular VA	2.16	0.59	0.42**	0.14**	-0.15	-0.03
R^2	0.53					
Adjusted R^2	0.51					
Mobility function						
Constant	-0.31	0.38			-0.38	0.79
Binocular threshold field score	-0.11	0.02	-0.54	0.44***	-0.17	-0.09
Binocular VA	1.08	0.53	0.25	0.04*	-0.21	-0.08
R^2	0.48					
Adjusted R^2	0.46					

b. Binocular suprathreshold	B	SE B	β	R^2 change	95% confidence interval	
Overall D-AI score					**Lower bound**	**Lower bound**
Constant	-1.62	0.45			0.13	2.64
Binocular VA	2.27	0.57	0.44***	0.39***	-2.64	-0.74
Binocular suprathreshold field score	-0.02	0.01	-0.43***	0.15***	-0.03	-0.01
R^2	0.54					
Adjusted R^2	0.52					
Mobility function					-0.28	1.05
Constant	-0.22	0.41			-0.04	-0.02
Binocular suprathreshold field score	-0.02	0.01	-0.52***	0.41***	-0.14	-0.02
Binocular VA	1.25	0.52	0.28*	0.07*		
R^2	0.48					
Adjusted R^2	0.45					

c. Binocular kinetic	B	SE B	β	R^2 change	95% confidence interval	
Overall D-AI score					**Lower bound**	**Lower bound**
Constant	-1.49	0.43			0.14	2.65
Binocular kinetic field score	0.00	0.00	-0.464***	0.41***	0.00	0.00
Binocular VA	2.23	0.55	0.44***	0.16***	0.90	2.36
R^2	0.57					
Adjusted R^2	0.55					
Mobility function						
Constant	-0.20	0.40			-0.75	0.74
Binocular kinetic field score	0.00	0.00	-0.53***	0.41***	0.00	0.00
Binocular VA	1.29	0.51	0.29*	0.07*	0.14	1.49
R^2	0.49					
Adjusted R^2	0.46					

d. Esterman	B	SE B	β	R^2 change	95% confidence interval	
Overall D-AI score					**Lower bound**	**Lower bound**
Constant	-1.43	0.47			0.37	2.88
Binocular VA	2.32	0.56	0.45***	0.39***	-2.67	-0.82

Esterman field score	-0.03	0.01	-0.44***	0.16***	-0.04	-0.01
R^2	0.55					
Adjusted R^2	0.53					
Mobility function						
Constant	-0.02	0.43			-0.61	1.02
Esterman field score	-0.03	0.01	-0.53***	0.42***	-0.04	-0.02
Binocular VA	1.30	0.50	0.30*	0.07*	0.07	1.44
R^2	0.49					
Adjusted R^2	0.47					

e. Integrated visual fields	**B**	**SE B**	**β**	**R^2 change**	**95% confidence interval**	
Overall D-AI score					**Lower bound**	**Lower bound**
Constant	-2.01	0.47			0.11	2.85
Binocular VA	2.50	0.61	0.49***	0.39***	-3.37	-1.65
IVF score	-0.06	0.02	-0.32**	0.08**	0.15	0.03
R^2	0.47					
Adjusted R^2	0.45					
Mobility function						
Constant	-0.40	0.42			-0.44	0.90
IVF score	-0.07	0.02	-0.47***	0.36***	-0.13	-0.06
Binocular VA	1.34	0.54	0.31*	0.08*	0.04	0.08
R^2	0.43					
Adjusted R^2	0.41					

Table 5.11 Results of stepwise regression analyses to determine which of the clinical variables best represents self-reported function. Visual field scores were entered into separate models. (B= unstandardised regression coefficients, SE B= standard errors, β= standardised regression coefficients R^2 change= amount of additional variance by including predictors from sample, Adjusted R^2= variance accounted for if derived from the population from which the sample was taken (Fields, 2005) (* $p< 0.05$, ** $p<0.01$, *** $p<0.001$).

The unstandardised regression coefficients of each model can be used to construct linear equations to predict overall self-reported function and mobility function. For example, in the multiple regressions with the binocular threshold field score entered:

Overall self-reported function = -1.78 + (-0.10 x binocular threshold field (dB) + (2.16 x binocular VA (LogMAR))

Mobility function = -0.31 + (-0.11 x binocular threshold field (dB)) + (1.08 x binocular VA (LogMAR))

Self-reported function can be estimated by inserting a single predictor variable value into these equations, provided that all other predictor variables remain constant. For example, from the unstandardised regression coefficients in Table 5.11, and the equations above, it can be predicted that as the binocular threshold field score decreases/worsens by 1dB, the mobility function score decreases/mobility is reported more difficult by 0.10 logits (±0.03), provided binocular VA remains constant. As the binocular suprathreshold or Esterman field scores decrease by 1%, self-reported mobility function is reported more difficult by 0.02 logits (±0.01) and 0.03 logits (±0.01) respectively. A similar reduction in mobility function (0.02 ±0.01) results from a loss of 100 deg^2 of the kinetic visual field.

Standardised regression coefficients (β) as shown in Table 5.11 are not dependent on the units of measurement of the predictor variables, because they are measured in standard deviation units. This enables the direct comparison of the relative influence of each predictor. Graphical representation of the relative influence of each visual field score plotted against self-reported mobility function is provided in Figure 5.18. As illustrated by the gradient of the plotted lines, all field scores are similarly effective at predicting perceived mobility function. The IVF may be a slightly worse indicator of self-reported mobility function compared to other methods of visual field assessment. From the results given in Table 5.11, the visual field score most strongly influences mobility related self-reported function for all field variables. A loss of one standard deviation of the average visual field score results in worse self-reported mobility function of between 0.47 and 0.54 standard deviations.

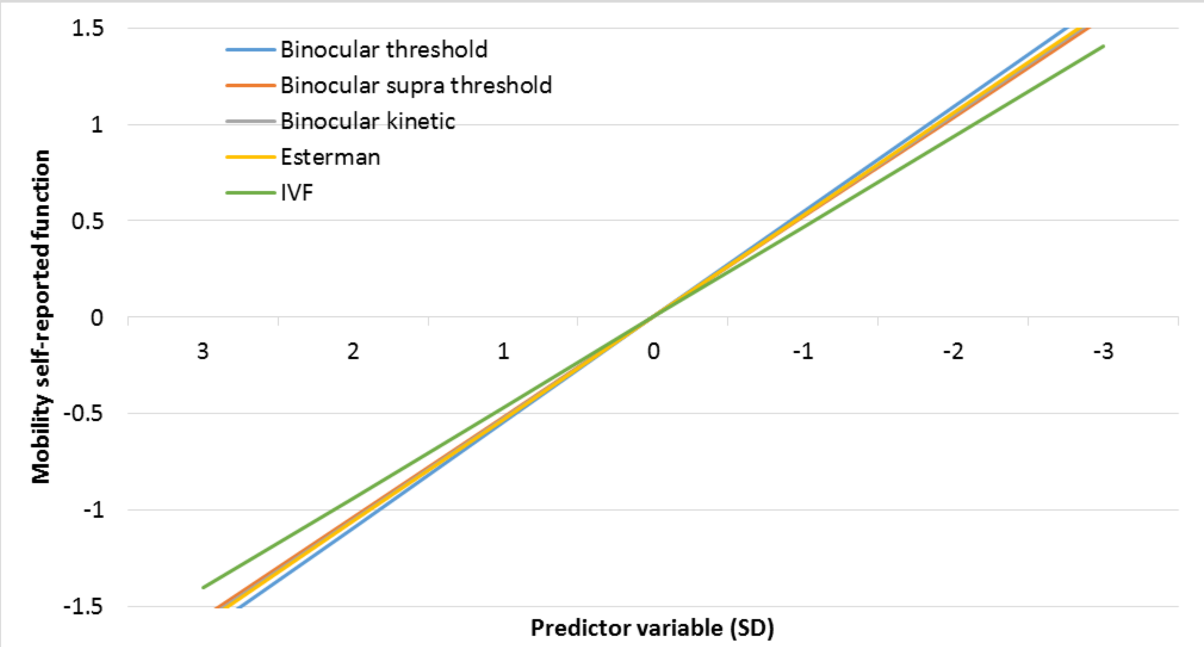


Figure 5.18 Graphical representations of the linear association of visual field variables against self-reported mobility function. The gradient of the line indicates the change in the self-reported function that would be associated with a specified change in the visual field. A steeper slope therefore indicates a stronger association between the visual field score and mobility function. The effects of all other predictors must be constant for these graphs to apply.

5.3.7 ROC analysis

A ROC analysis was performed using the binary responses to the 35 task questions of the IMQ. Areas under the curve that are significantly different from 0.5 at the 95% confidence interval are highlighted in Table 5.12, and suggest visual field scores that are able to distinguish between participants who report difficulty with a mobility task and those who do not (Schoonjans, 2017). ROC curves for different visual field scores were compared to evaluate how effective they were at selecting participants with perceived mobility difficulty (sensitivity), and without perceived mobility difficulty (specificity). Youden's J statistics were determined allowing the criterion for selecting the optimum cut-off point for each visual field assessment that would indicate perceived mobility difficulty to be estimated, and also summarized the performance of the visual field as a diagnostic test.

	Visual field variable	AUC	x (optimal cut-off point)	Sensitivity	Specificity	Youden's J
Walking in familiar areas	Binocular threshold (dB)	0.77(±0.08)*	8.02	0.75	0.71	0.46
	Binocular suprathreshold (%)	0.77(±0.08)*	13.07	0.58	0.94	0.53
	Binocular kinetic solid angle (deg^2)	0.78(±0.10)*	562.60	0.58	0.94	0.53
	Esterman (%)	0.76(±0.09)*	19.58	0.58	0.94	0.53
	Integrated visual field (dB)	0.71(±0.09)*	7.18	0.58	0.77	0.35
Walking in unfamiliar areas	Binocular threshold (dB)	0.82(±0.06)*	8.16	0.62	0.88	0.50
	Binocular suprathreshold (%)	0.84(±0.06)*	89.77	0.90	0.65	0.54
	Binocular kinetic solid angle (deg^2)	0.82(±0.06)*	8006.70	0.83	0.77	0.59
	Esterman (%)	0.80(±0.06)*	67.50	0.69	0.82	0.51
	Integrated visual field (dB)	0.75(±0.07)*	20.82	0.76	0.71	0.47
Moving about in the home	Binocular threshold (dB)	0.77(±0.07)*	6.79	0.73	0.71	0.44
	Binocular suprathreshold (%)	0.82(±0.07)*	17.61	0.64	0.89	0.52
	Binocular kinetic solid angle (deg^2)	0.83(±0.06)*	5438.30	0.91	0.74	0.65
	Esterman (%)	0.80(±0.07)*	58.33	0.91	0.59	0.60
	Integrated visual field (dB)	0.71(±0.08)*	20.82	0.91	0.51	0.42
Moving about at work	Binocular threshold (dB)	0.93(±0.06)*	5.53	1.00	0.79	0.79
	Binocular suprathreshold (%)	0.97(±0.03)*	17.61	1.00	0.90	0.90
	Binocular kinetic solid angle (deg^2)	0.95(±0.05)*	521.10	0.80	1.00	0.80
	Esterman (%)	0.95(±0.05)*	13.75	0.80	1.00	0.80
	Integrated visual field (dB)	0.90(±0.07)*	7.18	0.80	0.84	0.64
Moving about in the classroom						
Moving about in stores	Binocular threshold (dB)	0.84(±0.06)*	8.16	0.71	0.86	0.57
	Binocular suprathreshold (%)	0.85(±0.06)*	55.11	0.75	0.82	0.57
	Binocular kinetic solid angle (deg^2)	0.83(±0.06)*	7009.95	0.75	0.86	0.61
	Esterman (%)	0.85(±0.06)*	67.50	0.83	0.86	0.70
	Integrated visual field (dB)	0.79(±0.07)*	17.36	0.79	0.73	0.52
Moving about in outdoors	Binocular threshold (dB)	0.86(±0.06)*	11.59	0.94	0.71	0.66
	Binocular suprathreshold (%)	0.86(±0.05)*	66.48	0.94	0.68	0.62
	Binocular kinetic solid angle (deg^2)	0.84(±0.07)*	7355.70	0.89	0.75	0.64
	Esterman (%)	0.84(±0.06)*	67.50	0.83	0.71	0.55

	Integrated visual field (dB)	0.85(±0.06)*	20.82	1.00	0.68	0.68
Moving about in crowded situations	Binocular threshold (dB)	0.89(±0.05)*	14.12	0.83	0.81	0.65
	Binocular suprathreshold (%)	0.91(±0.04)*	71.59	0.83	0.88	0.71
	Binocular kinetic solid angle (deg^2)	0.90(±0.05)*	7216.40	0.73	1.00	0.73
	Esterman (%)	0.90(±0.05)*	67.50	0.77	1.00	0.77
	Integrated visual field (dB)	0.82(±0.07)*	20.82	0.83	0.88	0.71
Walking at night	Binocular threshold (dB)	0.90(±0.04)*	19.36	0.87	1.00	0.87
	Binocular suprathreshold (%)	0.89(±0.04)*	78.98	0.77	1.00	0.77
	Binocular kinetic solid angle (deg^2)	0.88(±0.05)*	8782.15	0.80	1.00	0.80
	Esterman (%)	0.90(±0.04)*	88.75	0.82	1.00	0.82
	Integrated visual field (dB)	0.89 (±0.04)*	25.59	0.82	1.00	0.82
Using public transport	Binocular threshold (dB)	0.78(±0.07)*	9.30	0.82	0.75	0.57
	Binocular suprathreshold (%)	0.79(±0.07)*	63.07	0.88	0.68	0.56
	Binocular kinetic solid angle (deg^2)	0.78(±0.08)*	7216.40	0.88	0.79	0.67
	Esterman (%)	0.75(±0.08)*	63.33	0.82	0.75	0.57
	Integrated visual field (dB)	0.74(±0.08)*	20.82	0.88	0.61	0.49
Detecting ascending stairwells	Binocular threshold (dB)	0.73(±0.08)*	19.36	1.00	0.50	0.50
	Binocular suprathreshold (%)	0.72(±0.08)*	78.98	0.91	0.50	0.50
	Binocular kinetic solid angle (deg^2)	0.73(±0.08)*	8234.25	0.91	0.63	0.50
	Esterman (%)	0.75(±0.07)*	77.50	0.82	0.67	0.49
	Integrated visual field (dB)	0.70(±0.08)*	22.27	0.86	0.58	0.45
Detecting descending stairwells	Binocular threshold (dB)	0.76(±0.09)*	14.12	0.77	0.73	0.51
	Binocular suprathreshold (%)	0.77(±0.09)*	89.77	0.87	0.67	0.54
	Binocular kinetic solid angle (deg^2)	0.72(±0.09)*	8608.80	0.81	0.67	0.47
	Esterman (%)	0.73(±0.09)*	83.75	0.77	0.67	0.44
	Integrated visual field (dB)	0.71(±0.08)*	23.57	0.74	0.73	0.48
Walking up steps	Binocular threshold (dB)	0.59(±0.08)	19.66	1.00	0.37	0.37
	Binocular suprathreshold (%)	0.59(±0.08)	89.77	0.96	0.48	0.44
	Binocular kinetic solid angle (deg^2)	0.62(±0.08)	9288.45	0.96	0.48	0.44
	Esterman (%)	0.62(±0.08)	68.75	0.73	0.63	0.36
	Integrated visual field (dB)	0.56(±0.09)	20.82	0.56	0.56	0.33
Walking down steps	Binocular threshold (dB)	0.77(±0.09)*	14.12	0.81	0.68	0.49
	Binocular suprathreshold (%)	0.74(±0.08)*	89.77	0.90	0.63	0.54

	Binocular kinetic solid angle (deg^2)	0.71(±0.08)*	9288.45	0.90	0.63	0.54
	Esterman (%)	0.72(±0.09)*	83.75	0.81	0.63	0.44
	Integrated visual field (dB)	0.72(±0.09)*	22.41	0.81	0.63	0.41
Stepping onto curbs	Binocular threshold (dB)	0.72(±0.07)*	8.03	0.62	0.79	0.41
	Binocular suprathreshold (%)	0.70(±0.08)*	71.59	0.81	0.63	0.43
	Binocular kinetic solid angle (deg^2)	0.71(±0.08)*	6254.70	0.65	0.79	0.44
	Esterman (%)	0.71(±0.07)*	68.75	0.73	0.71	0.44
	Integrated visual field (dB)	0.71(±0.08)*	20.82	0.77	0.63	0.39
Stepping off curbs	Binocular threshold (dB)	0.73(±0.08)*	14.12	0.77	0.60	0.37
	Binocular suprathreshold (%)	0.73(±0.08)*	71.59	0.77	0.65	0.42
	Binocular kinetic solid angle (deg^2)	0.71(±0.08)*	9288.45	0.87	0.55	0.42
	Esterman (%)	0.69(±0.08)*	68.75	0.67	0.70	0.37
	Integrated visual field (dB)	0.69(±0.08)*	20.82	0.73	0.65	0.38
Walking through doorways	Binocular threshold (dB)	0.81(±0.06)*	2.10	0.55	0.97	0.52
	Binocular suprathreshold (%)	0.79 (±0.07)*	51.14	0.70	0.73	0.43
	Binocular kinetic solid angle (deg^2)	0.80(±0.07)*	5264.70	0.75	0.77	0.52
	Esterman (%)	0.81(±0.06)*	58.33	0.75	0.77	0.52
	Integrated visual field (dB)	0.79(±0.07)*	6.13	0.60	0.90	0.50
Walking in high-glare areas	Binocular threshold (dB)	0.70(±0.12)	19.49	0.83	0.63	0.46
	Binocular suprathreshold (%)	0.70(±0.11)	97.16	0.91	0.50	0.41
	Binocular kinetic solid angle (deg^2)	0.84(±0.09)*	9918.45	0.93	0.63	0.55
	Esterman (%)	0.78(±0.09)*	91.25	0.83	0.63	0.46
	Integrated visual field (dB)	0.66(±0.10)	25.20	0.79	0.63	0.41
Adjusting to lighting changes during the day: Indoor to outdoor	Binocular threshold (dB)	0.73(±0.08)*	18.34	0.81	0.62	0.43
	Binocular suprathreshold (%)	0.78(±0.08)*	74.43	0.76	0.69	0.45
	Binocular kinetic solid angle (deg^2)	0.75(±0.07)*	8006.70	0.73	0.77	0.50
	Esterman (%)	0.73(±0.08)*	71.25	0..65	0.77	0.48
	Integrated visual field (dB)	0.71(±0.08)*	26.46	0.87	0.62	0.55
Adjusting to lighting changes during the day: Outdoor to indoor	Binocular threshold (dB)	0.82(±0.07)*	15.36	0.78	0.77	0.50
	Binocular suprathreshold (%)	0.84(±0.07)*	74.43	0.81	0.85	0.66
	Binocular kinetic solid angle (deg^2)	0.78(±0.07)*	8608.80	0.78	0.77	0.55
	Esterman (%)	0.78(±0.08)*	85.42	0.81	0.77	0.58
	Integrated visual field (dB)	0.83(±0.07)*	21.74	0.76	0.85	0.60

Adjusting to lighting changes at night: Indoor to streetlights	Binocular threshold (dB)	0.81(±0.08)*	19.49	0.88	0.70	0.58
	Binocular suprathreshold (%)	0.83(±0.07)*	74.43	0.75	0.80	0.55
	Binocular kinetic solid angle (deg^2)	0.79(±0.08)*	7216.40	0.58	0.90	0.48
	Esterman (%)	0.81(±0.08)*	71.25	0.65	0.90	0.55
	Integrated visual field (dB)	0.82(±0.08)*	26.46	0.85	0.70	0.55
Adjusting to lighting changes at night: Streetlights to indoor	Binocular threshold (dB)	0.67(±0.08)*	19.36	0.89	0.42	0.31
	Binocular suprathreshold (%)	0.67(±0.08)*	74.43	0.81	0.54	0.35
	Binocular kinetic solid angle (deg^2)	0.67(±0.08)*	8006.70	0.81	0.63	0.43
	Esterman (%)	0.67(±0.08)*	71.25	0.69	0.63	0.32
	Integrated visual field (dB)	0.66(±0.08)*	21.74	0.73	0.54	0.27
Walking in dimly lit indoor areas	Binocular threshold (dB)	0.72(±0.10)*	19.49	0.87	0.64	0.51
	Binocular suprathreshold (%)	0.69(±0.10)	78.98	0.74	0.64	0.38
	Binocular kinetic solid angle (deg^2)	0.66(±0.10)	8782.15	0.74	0.64	0.38
	Esterman (%)	0.69(±0.10)	88.75	0.80	0.64	0.43
	Integrated visual field (dB)	0.67(±0.11)	27.04	0..87	0.64	0.51
Being aware of another person's presence	Binocular threshold (dB)	0.86(±0.06)*	19.36	1.00	0.65	0.65
	Binocular suprathreshold (%)	0.85(±0.06)*	74.43	0.90	0.75	0.65
	Binocular kinetic solid angle (deg^2)	0.83(±0.06)*	8234.25	0.90	0.80	0.70
	Esterman (%)	0.86(±0.06)*	81.25	0.77	0.80	0.57
	Integrated visual field (dB)	0.82(±0.07)*	21.74	0.83	0.75	0.58
Avoiding bumping into: People	Binocular threshold (dB)	0.83(±0.06)*	14.12	0.84	0.74	0.58
	Binocular suprathreshold (%)	0.82(±0.06)*	71.59	0.84	0.79	0.63
	Binocular kinetic solid angle (deg^2)	0.86(±0.05)*	7216.40	0.74	0.95	0.69
	Esterman (%)	0.85(±0.05)*	68.75	0.77	0.90	0.70
	Integrated visual field (dB)	0.78(±0.07)*	20.82	0.81	0.79	0.60
Avoiding bumping into: Walls	Binocular threshold (dB)	0.73(±0.07)*	2.28	0.46	0.92	0.38
	Binocular suprathreshold (%)	0.77(±0.07)*	71.59	0.79	0.58	0.37
	Binocular kinetic solid angle (deg^2)	0.77(±0.07)*	7009.95	0.71	0.77	0.48
	Esterman (%)	0.77(±0.07)*	61.25	0.71	0.77	0.48
	Integrated visual field (dB)	0.70(±0.08)*	23.59	0.88	0.46	0.34
Avoiding bumping into: Head-height objects	Binocular threshold (dB)	0.85(±0.07)*	19.36	0.90	0.82	0.72
	Binocular suprathreshold (%)	0.83(±0.07)*	79.98	0.80	0.82	0.61
	Binocular kinetic solid angle (deg^2)	0.83(±0.07)*	8782.15	0.82	0.91	0.73

	Esterman (%)	0.83(±0.07)*	88.75	0.85	0.82	0.66
	Integrated visual field (dB)	0.84(±0.08)*	25.59	0.85	0.82	0.66
Avoiding bumping into: Shoulder-height objects	Binocular threshold (dB)	0.87(±0.07)*	15.36	0.89	0.65	0.54
	Binocular suprathreshold (%)	0.79(±0.07)*	74.43	0.93	0.70	0.62
	Binocular kinetic solid angle (deg^2)	0.82(±0.06)*	8006.70	0.89	0.74	0.63
	Esterman (%)	0.80(±0.06)*	83.75	0.89	0.65	0.54
	Integrated visual field (dB)	0.75(±0.07)*	21.74	0.85	0.70	0.55
Avoiding bumping into: Waist-height objects	Binocular threshold (dB)	0.78(±0.07)*	13.07	0.86	0.59	0.44
	Binocular suprathreshold (%)	0.81(±0.06)*	21.59	0.57	0.90	0.47
	Binocular kinetic solid angle (deg^2)	0.81(±0.07)*	7009.95	0.81	0.79	0.60
	Esterman (%)	0.82(±0.06)*	61.25	0.81	0.79	0.60
	Integrated visual field (dB)	0.71(±0.08)*	20.82	0.81	0.59	0.40
Avoiding bumping into: Knee-height objects	Binocular threshold (dB)	0.82(±0.06)*	4.05	0.53	1.00	0.53
	Binocular suprathreshold (%)	0.82(±0.06)*	26.14	0.53	1.00	0.53
	Binocular kinetic solid angle (deg^2)	0.78(±0.07)*	7009.95	0.70	0.90	0.60
	Esterman (%)	0.83(±0.06)*	71.25	0.80	0.85	0.65
	Integrated visual field (dB)	0.75(±0.07)*	21.74	0.77	0.65	0.42
Avoiding bumping into: Low-lying objects	Binocular threshold (dB)	0.79 (±0.07)*	19.36	0.93	0.52	0.46
	Binocular suprathreshold (%)	0.77(±0.07)*	89.77	0.93	0.62	0.55
	Binocular kinetic solid angle (deg^2)	0.80(±0.07)*	89.77	0.86	0.71	0.58
	Esterman (%)	0.78(±0.07)*	51.21	0.83	0.81	0.64
	Integrated visual field (dB)	0.70(±0.08)*	22.41	0.83	0.62	0.45
Avoiding tripping over uneven travel surfaces	Binocular threshold (dB)	0.65(±0.12)	19.68	0.90	0.50	0.40
	Binocular suprathreshold (%)	0.65(±0.12)	74.43	0.73	0.70	0.43
	Binocular kinetic solid angle (deg^2)	0.67(±0.12)	9288.45	0.80	0.70	0.50
	Esterman (%)	0.60(±0.11)	71.25	0.60	0.70	0.30
	Integrated visual field (dB)	0.63(±0.13)	28.30	0.90	0.50	0.40
Moving around in social gatherings	Binocular threshold (dB)	0.86(±0.05)*	15.36	0.93	0.73	0.66
	Binocular suprathreshold (%)	0.86(±0.06)*	74.43	0.96	0.23	0.74
	Binocular kinetic solid angle (deg^2)	0.83(±0.06)*	8234.25	0.93	0.77	0.70
	Esterman (%)	0.86(±0.06)*	71.25	0.86	0.86	0.72
	Integrated visual field (dB)	0.82(±0.06)*	21.74	0.89	0.77	0.67
	Binocular threshold (dB)	0.83(±0.06)*	9.30	0.81	0.76	0.57

Finding restrooms in public places	Binocular suprathreshold (%)	0.83(±0.06)*	26.14	0.67	0.93	0.60
	Binocular kinetic solid angle (deg^2)	0.84(±0.06)*	7216.40	0.91	0.83	0.73
	Esterman (%)	0.82(±0.06)*	61.25	0.81	0.79	0.60
	Integrated visual field (dB)	0.78(±0.07)*	7.18	0.62	0.90	0.52
Seeing cars at intersections	Binocular threshold (dB)	0.76(±0.08)*	15.36	0.87	0.70	0.57
	Binocular suprathreshold (%)	0.74(±0.08)*	78.98	0.90	0.70	0.60
	Binocular kinetic solid angle (deg^2)	0.78(±0.08)*	8234.25	0.90	0.80	0.70
	Esterman (%)	0.78(±0.07)*	83.75	0.87	0.70	0.57
	Integrated visual field (dB)	0.73(±0.08)*	22.41	0.87	0.70	0.57

Table 5.12 Receiver operating characteristics (ROC) areas under the curves (AUC) describing the relative performance of the difference visual field scores in predicting self-reported function in mobility related tasks. Also provided are the calculated sensitivity and specificity values for each task question, and optimal discrimination points as determined by Youden's J statistic (J= Sensitivity+ Specificity -1). There was not sufficient responses to the task "moving about in the classroom" to determine these statistics. *indicates AUCs that are significantly ($p \leq 0.05$) different from 0.50.

The areas under the ROC curves for all visual field assessments suggest all tests are good indicators of at least some self-reported function in mobility tasks (Table 5.12). Areas under the curve range from 0.60 to 0.97, and approximately 90% of AUCs for all visual field scores are significantly ($p \leq 0.05$) different from 0.50 indicating that field scores were able to distinguish between participants who report difficulty with the mobility task and those who do not. Areas under the ROC curves for the tasks "walking up steps" and "avoiding tripping over uneven travel surfaces" were not significantly different from 0.5 at the 95% confident interval suggesting that none of the visual field scores were effective predictors of difficulty with these tasks. Mobility tasks with the highest average AUC were moving around at work (0.94±0.02), walking around at night (0.90±0.02), and walking in crowded situations (0.89±0.02) suggesting that the visual fields assessments were more accurate at predicting perceived difficulty with these tasks. Adjusting to light changes at night when moving from a streetlights to indoors (0.67±0.01), and walking in high glare areas (0.68±0.03) had the lowest average AUCs.

A statistical technique appropriate where two measures are applied to the same set of participants were used to determine any statistically significant differences between areas under the ROC curves and establish if a visual field test was better at predicting a perceived visual function (DeLong et al., 1988), and are highlighted in Figure 5.19. The binocular threshold and binocular suprathreshold assessments are better than the IVF at predicting difficulty walking in familiar areas, walking in unfamiliar areas, walking at home, walking in crowded areas, avoiding bumping into knee height objects, and finding public toilets. The binocular threshold assessment is also better than the IVF at predicting difficulty avoiding bumping into people, while the Esterman was found to better predict difficulty walking in high glare. All three custom tests and the Esterman assessment were better than the IVF at predicting difficulty avoiding bumping into waist height objects, and at predicting difficulty avoiding bumping into low lying objects. Complete results of these comparisons are provided in Table 5.13.

The average binocular threshold field score optimal cut-off point for predicting perceived mobility estimated using Youden's J, was 13.55dB(±0.96), suggesting that participants lost a considerable degree of their binocular threshold field score before reporting mobility difficulty (13.55dB). The optimal cut off point was similar for the binocular suprathreshold (66.27% ±4.05) and Esterman (69.34% ±2.88) field scores indicating that participants lost a similar percentage of field as determined with either suprathreshold assessment before perceiving difficulty with mobility tasks. The optimal cut off point was 20.73dB (±0.96) for IVF score, and 7212.02deg^2 (±2661.55) for kinetic field score.

The optimal cut off point was higher across all field scores for some mobility tasks such as walking in high glare. Participants with a binocular threshold field score less than 19.49dB, binocular suprathreshold score of less than 97.16%, a binocular kinetic score of less than 9918.45 deg^2, an Esterman score of less than 91.25%, or an IVF score of less than 25.20dB, are predicted to report difficulty with this mobility task. The high optimal cut off points and low AUC averaged across field types for this task suggest that while walking in high glare is a difficult task, difficulty may be more sensitive to smaller losses in other aspects of visual function, for example contrast sensitivity. For other tasks, such as moving around at work, the AUCs were higher and the visual field score cut off points were lower suggesting that the visual field is very relevant to these tasks, but there needs to be a reasonable amount of damage before function is noticeably affected. Participants with a binocular threshold score less than 5.53dB, binocular suprathreshold score less than 17.61%, binocular kinetic score less than 521.10 deg^2, an Esterman score less than 13.75%, or an IVF score less than 7.18dB reported difficulty with this task.

Mobility task	Visual field tests being compared	Difference between areas (±std)	z statistic	Significance value
Walking in familiar areas	Binocular threshold* IVF	0.06(±0.03)	2.18	0.029
Walking in familiar areas	Binocular suprathreshold* IVF	0.08(±0.03)	2.20	0.028
Walking in unfamiliar areas	Binocular threshold * IVF	0.07(±0.03)	2.23	0.026
Walking in unfamiliar areas	Binocular suprathreshold* IVF	0.08(±0.04)	2.11	0.035
Walking at home	Binocular suprathreshold* Binocular threshold	0.05(±0.02)	2.09	0.037
Walking at home	Binocular suprathreshold* IVF	0.10(±0.03)	3.10	0.002
Walking at home	Binocular kinetic* IVF	0.12(±0.05)	2.57	0.010
Walking in crowded areas	Binocular threshold * IVF	0.07(±0.03)	2.11	0.035
Walking in crowded areas	Binocular suprathreshold* IVF	0.10(±0.04)	2.33	0.020
Walking in high glare areas	Esterman* Binocular threshold	0.08(±0.04)	2.01	0.044
Walking in high glare areas	Binocular kinetic* IVF	0.18(±0.08)	2.25	0.025
Walking in high glare areas	Esterman* IVF	0.12(±0.05)	2.20	0.028
Avoiding bumping into people	Binocular threshold* IVF	0.05(±0.03)	2.07	0.038

Avoiding bumping into waist height objects	Binocular threshold* IVF	0.06(±0.02)	2.74	0.006
Avoiding bumping into waist height objects	Binocular suprathreshold* IVF	0.10(±0.03)	3.37	0.001
Avoiding bumping into waist height objects	Binocular kinetic* IVF	0.10(±0.04)	2.33	0.020
Avoiding bumping into waist height objects	Esterman* IVF	0.10(±0.04)	2.72	0.007
Avoiding bumping into knee height objects	Binocular threshold* IVF	0.06(±0.02)	2.65	0.008
Avoiding bumping into knee height objects	Binocular suprathreshold* IVF	0.07(±0.03)	2.35	0.019
Avoiding bumping into low lying objects	Binocular threshold * IVF	0.08(±0.02)	3.56	0.001
Avoiding bumping into low lying objects	Binocular suprathreshold* IVF	0.07(±0.03)	2.21	0.027
Avoiding bumping into low lying objects	Binocular kinetic* IVF	0.10(±0.04)	2.26	0.024
Avoiding bumping into low lying objects	Esterman* IVF	0.08(±0.04)	2.03	0.042
Finding public toilets	Binocular threshold * IVF	0.05(±0.02)	2.34	0.020

Table 5.13. Results of statistical comparisons between the visual field assessments' AUCs. Differences between the areas, the z statistic (DeLong et al., 1988) and its significance level are given. All other comparisons were non-significant. *indicates the visual field assessment with a statistically significant greater AUC.

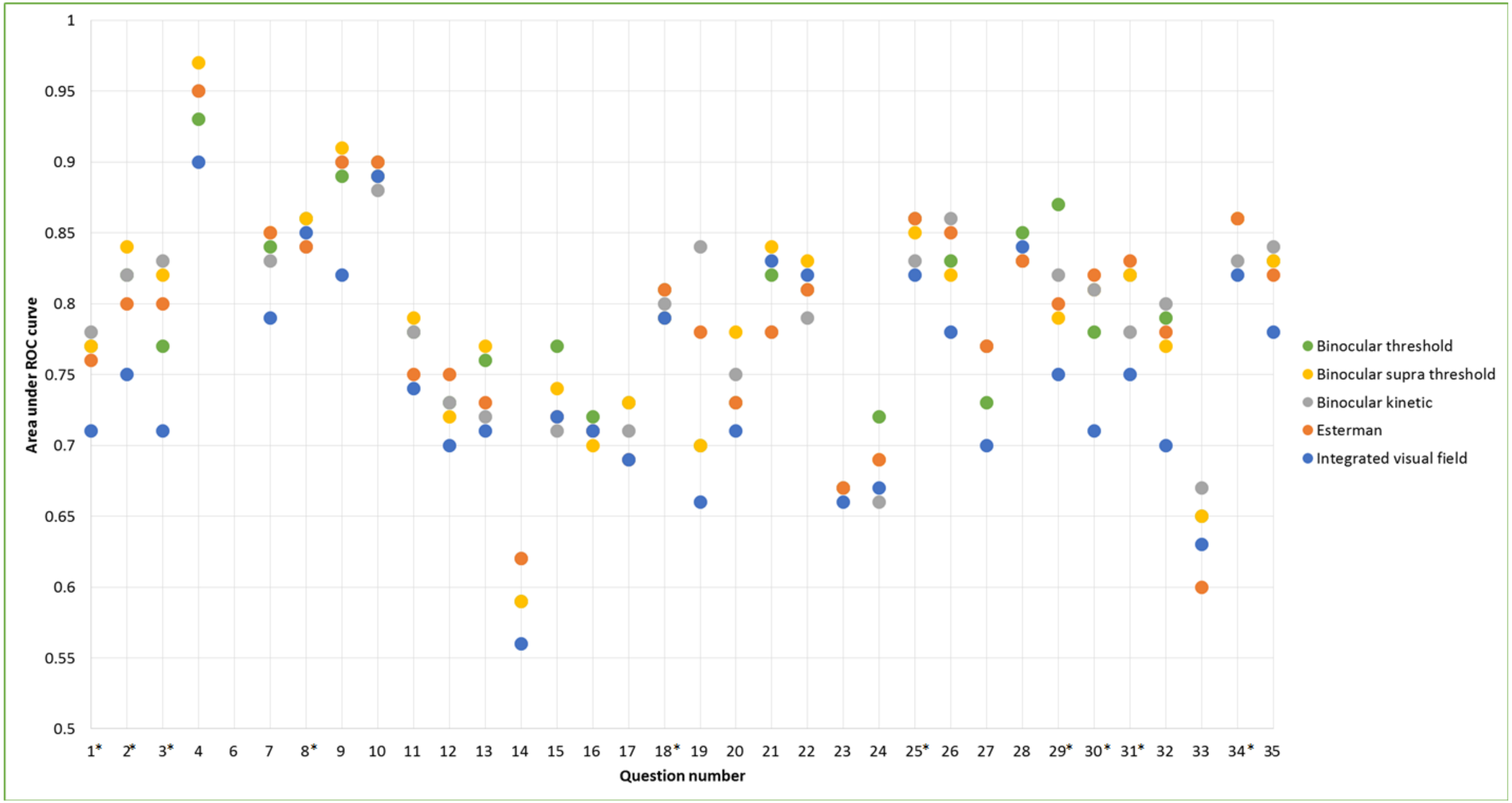


Figure 5.19 Graphical representation of areas under ROC curves for the difference visual field tests. The questions to which the numbers on the x-axis refer are given in Table 1. * indicates a visual field assessment with a statistically significant greater area under the curve (AUC) than an alternative assessment. All other comparisons were non-significant.

5.3.9 Derived suprathreshold vs measured suprathreshold scores

To investigate if altering the suprathreshold stimulus intensity would improve the visual field assessment's ability to predict self-reported function, a further analysis of the threshold visual field data involved converting the mean threshold values into dichotomous suprathreshold results in the same way as Experiment 1. Since the same custom test pattern was used for binocular threshold and suprathreshold assessments, a comparison of derived and measured suprathreshold field scores could be made. Six cut off points were used to define stimulus intensity in 5dB increments from 0dB until 25dB. Test points with a threshold greater than the cut off point were recorded as seen, and all points with a threshold value less than the cut off stimulus intensity were recorded as unseen (Figure 5.20). The suprathreshold visual field score was expressed as the total number of points seen in the overall visual field out of a possible 88. Descriptive statistics of the derived scores are provided in Table 5.14.

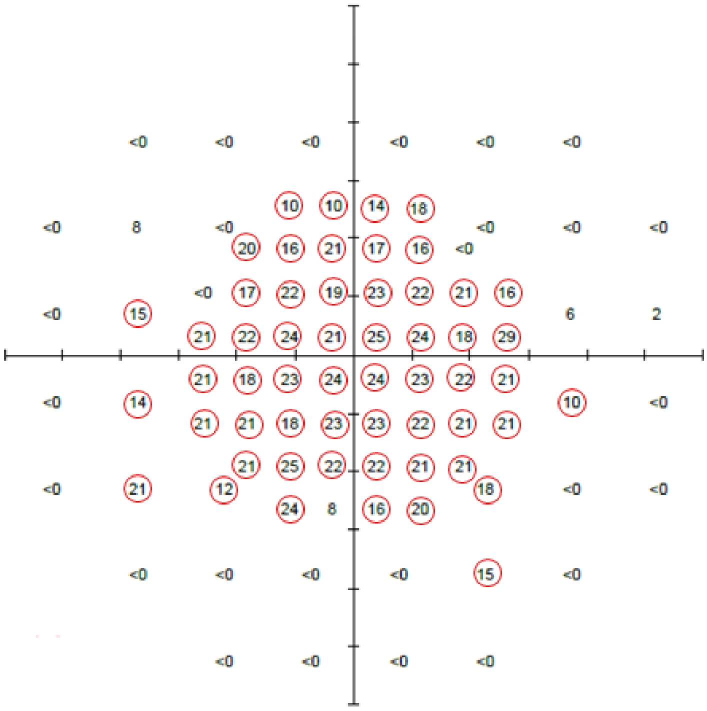


Figure 5.20 Example visual field results demonstrating how the suprathreshold visual field scores are calculated for 10dB stimulus intensity. All test points with a mean threshold of ≥10dB are recorded as seen, and are shown as the circled points on this diagram. All other points are recorded as unseen. The suprathreshold visual field score is the sum of all the points seen.

Derived suprathreshold score: stimulus intensity	Mean (±std)	Median (25% IQ-75% IQ))	Range
0dB	61.07(±5.00)	69.32(29.55-96.59)	1.55-100.00
5dB	55.61(±5.17)	60.23(17.05-94.32)	2.27-98.86
10dB	49.95(±5.16)	50.00(10.23-90.91)	1.14-98.86
15dB	41.20(±4.92)	34.66(5.68-78.41)	0.00-96.59
20dB	30.27(±4.29)	21.02(2.27-56.82)	0.00-94.32
25dB	14.18(±2.70)	4.55(0.00-23.86)	0.00-68.18

Table 5.14 Descriptive statistics of derived suprathreshold scores at different stimulus intensity cut off points. The mean ± standard deviation, and the median (interquartile range) are given.

The measured suprathreshold score was almost perfectly correlated with the derived scores using the same 10dB stimulus (R^2=0.94, p<0.001). All derived visual field score were highly correlated with each other, and with measured threshold and suprathreshold scores (Table 5.15, Figure 5.21), reflecting results of Experiment 1 analysis.

	Threshold field score	Measured suprathresh-old score	Derived supra: 0dB	Derived supra: 5dB	Derived supra: 10dB	Derived supra: 15dB	Derived supra: 20dB	Derived supra: 25dB
Threshold field score								
Measured suprathresh-old score	0.93*							
Derived supra: 0dB	0.91*	0.92*						
Derived supra: 5dB	0.95*	0.94*	0.97*					
Derived supra: 10dB	0.98*	0.94*	0.93*	0.97*				
Derived supra: 15dB	0.97*	0.89*	0.87*	0.92*	0.96*			
Derived supra: 20dB	0.94*	0.84*	0.80*	0.86*	0.91*	0.95*		
Derived supra: 25dB	0.81*	0.70*	0.69*	0.70*	0.77*	0.82*	0.87*	

Table 5.15 Correlation matrix showing the relationship between the measured and derived suprathreshold field scores (*p<0.001).

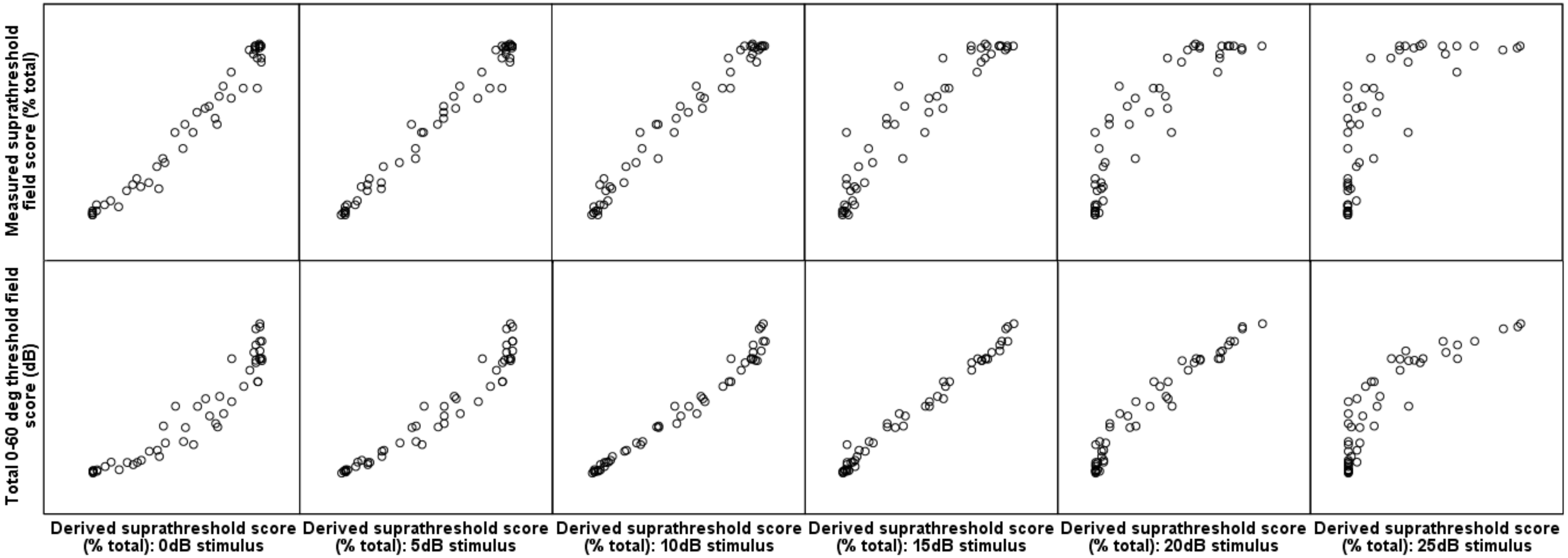


Figure 5.21. Relationship between measured threshold and suprathreshold field scores, and derived scores using different stimulus intensities as a cut off.

Bivariate analyses were also conducted to investigate whether altering the stimulus intensity provided a derived field score that better predicted self-reported function. All derived scores and the measured threshold and suprathreshold field scores relate similarly to perceived function (Table 5.16).

Derived suprathreshold score: stimulus intensity	**Overall D-AI score (R^2)**	**Mobility function (R^2)**
0dB	0.32*	0.38*
5dB	0.38*	0.44*
10dB	0.41*	0.45*
15dB	0.41*	0.43*
20dB	0.42*	0.47*
25dB	0.40*	0.44*
Measured suprathreshold	0.40*	0.47*
Threshold field score	0.42*	0.47*

Table 5.16 Bivariate analysis between overall D-AI and self-reported mobility function and derived suprathreshold field scores. Non parametric 2-tailed Spearman's correlations coefficients are used (*p<0.001).

5.4 Discussion

While previous studies have shown binocular visual fields to relate to function, no previous study has directly compared different visual field paradigms to determine which methods best reflect functional ability. To determine the most appropriate method of assessing the functional visual field in individuals with low vision, different visual field assessments were related to self-reported function. Binocular visual field tests can reflect self-reported mobility function. Analyses indicate a similar relationship between perceived mobility function and the visual field regardless of the method of assessment.

Glaucoma accounted for the greatest proportion of the current sample (46%), and the proportion of participants with RP in this experiment was slightly less than in the previous study (28%). Men made up 58% of the sample, similar to the previous study. The median age in the present study was a little greater however (64yrs). The median duration of visual impairment for the sample was 14 years indicating established visual impairment. While the proportion of participants who reported using a mobility aid (46%) was greater than in the previous experiment (38%), a smaller proportion of the sample reported using low vision aids in the current study (30% in the present study, 44% in Experiment 1). A similar proportion of the participants in the current sample had registered their sight loss (52%) as compared to Experiment 1 (54%). Approximately two thirds of the sample in both experiments reported living with at least one family member, and half were still in full time employment.

Walking around at night was the most difficult task of the IMQ ($\bar{x}$=3.37 ±0.22), followed by walking in high glare areas ($\bar{x}$=3.20 ±0.19). Similarly Bibby et al., (2007) found the same two items were reported most difficult in small heterogeneous sample (n=30) of low vision patients. Walking around at night was also one of the most difficult items reported in a group of 40 participants with RP (Fenwick et al., 2016), and the most difficult reported item in the original validation study in RP patients (Turano et al., 1999). In a sample of glaucoma patients, Turano et al., (2002) found that walking high glare areas was the more difficult reported item, followed by walking around at night.

The clinical variables indicate a similar average degree of visual function between the samples in both experiments. Average binocular visual acuity ($\bar{x}$=0.29±0.07 LogMAR for Experiment 1 and $\bar{x}$=0.28±0.08 LogMAR for Experiment 2) and binocular CS ($\bar{x}$=1.46±0.08 LogCS for Experiment 1 and $\bar{x}$=1.51±0.07 LogCS for Experiment 2) are almost identical between the two studies.

Sight loss registration was again found to significantly relate to overall (R^2=0.43, p<0.001) and mobility self-reported function (R^2=0.47, p<0.001). Participants registered as severely sight impaired reported greater overall difficulty. Similarly to Experiment 1, the duration of visual impairment, and the use of mobility and low vision aids were also associated with greater self-reported function. All measures of clinical function relate similarly to self-reported function compared with the previous study.

The average binocular threshold field score in the current study ($\bar{x}$=10.87±1.19dB) is similar to the binocular threshold score derived in Experiment 1 ($\bar{x}$=11.70±1.36dB) despite the different methods of field assessment. Both assessments also relate similarly to overall (Experiment 1 R^2=0.50, Experiment 2 R^2=0.42) and mobility (Experiment 1 R^2=0.64, Experiment 2 R^2=0.47) self-reported function, and explain a similar degree of variance in self-reported mobility function. This suggests that a binocular threshold assessment of the visual field out to 60 degrees in a good indicator of perceived function with either number and pattern of test points, and either thresholding strategy employed. A wide field binocular threshold test with fewer test points might be quicker and as effective at predicting self-reported function.

Few studies have assessed the visual field binocularly using a threshold paradigm. Leat & Lovie-Kitchin (2010) assessed the central 30 degrees of the visual field using the SITA Fast strategy on the HFA, using the mean deviation (MD) and pattern standard deviation (PSD) as the main outcome measures. Scores were found to predict performance on useful field of vision (UFoV) tasks involving the detection of shapes in the central field (MD R^2=0.37 p<0.001, PSD R^2=0.55 p<0.001). Tabrett & Latham (2012) also used a binocular threshold test to assess the central 30 degrees of the visual field, and related average threshold field scores to self-reported function. They found that the visual field related significantly to overall (R^2=0.43-0.51) and mobility self-reported function (R^2 0.36 to 0.61, p<0.001 for all).

The binocular suprathreshold assessment related similarly to overall self-report (R^2=0.40, p<0.001) and mobility self-report (R^2=0.47, p<0.001) when compared with binocular threshold results, indicating that determining the threshold values of the 88 points, assessed in both tests, did not provide further information about perceived function, and that a quicker suprathreshold paradigm is just as effective as predicting self-reported function. This reflects the preliminary analysis in the previous analysis using a derived suprathreshold score.

Similarly to the current study, Jampel et al., (2002a) created custom binocular suprathreshold fields assessments that were performed on 101 patients with glaucoma. Stimulus intensity varied between 20dB and 26dB, and the central 30 degrees and peripheral 30 to 60 degrees field areas were assessed separately. The relationship between the four custom tests and self-reported function were fair, and R squared values varied from 0.24 – 0.28 (p<0.001 for all). Variance in findings between the current study and Jampel et al., are likely due to the difference in the methods assessing the visual field. They conducted their fields assessments on the HFA, using stimuli intensity dimmer than the 10dB that was utilised in this experiment. There are also significant differences in the point patterns of fields tests used in either study, with Jampel et al., (2002a) assessing central and peripheral field areas separately.

While it has been suggested a decreased suprathreshold stimulus intensity would expand the useful range of scores of a suprathreshold assessment (Choy et al., 1986; Harris & Jacobs, 1995), Jampel and colleagues' attempt at decreasing the Esterman stimulus intensity from 10dB to 20-26dB did not improve its ability to predict self-reported function. A preliminary analysis of Experiment 1 data using derived suprathreshold scores (Chapter 4) reflected this. A supplementary analysis using the current data involved using six cut off points to define stimulus intensity in 5dB increments from 0dB to 25dB. Derived scores using all six cut off points related similarly (R^2=0.38-0.47) to self-reported mobility function. In keeping with findings from Jampel et al., (2002a) this suggests that decreasing the stimulus intensity of a binocular suprathreshold assessment does not improve its ability to predict perceived function. It is possible that decreasing the stimulus intensity of a suprathreshold assessment might increase the range of scores and improve the test's ability to predict function in individuals with early to moderate visual field loss. In this current sample however, using a decreased stimulus intensity to determine derived suprathreshold results does not improve the ability of a visual fields test to predict self-reported function. This likely reflects the relatively severe degree of visual field loss that the sample exhibited, but may also indicate that it is the maximum extent of the visual field to a bright stimulus, and not losses within it that is important when considering functional ability

The binocular kinetic assessment related similarly to overall self-report (R^2=0.41, $p<0.001$) and mobility self-report (R^2=0.48, $p<0.001$) when compared with binocular threshold and suprathreshold results. This reflects the preliminary analysis in the previous analysis using a derived suprathreshold and kinetic scores.

Numerous other studies have also used a binocular kinetic field assessment (Choy et al., 1986; Lovie-Kitchin et al., 1990; Haymes et al., 1996; Haymes et al., 2002; Bibby et al., 2007; Sugawara et al., 2009). Haymes et al., (1996) used the Goldmann perimeter and a III-4e target to assess the binocular field of RP subjects and compared field results to mobility performance. A scoring method devised to represent the residual visual field involved rating the amount of extension of peripheral visual field loss into the central visual field (RP Concentric Field Rating), which relates similarly to indoor mobility function (R^2=0.41-0.59, $p<0.05$) when compared with results of the current study. A binocular kinetic Goldmann assessment has also been compared to self-reported mobility in mixed low vision samples (Haymes et al., 2002; Bibby et al., 2007) and a sample of RP patients (Sugawara et al., 2009). Similar correlations were found. Lovie-Kitchin et al., (1990) assessed the binocular visual field kinetically using a Hablin Lister arc perimeter in a small sample of subjects, of which half had mixed visual impairment, and scored the residual field as a solid angle in steradians. Mobility performance was assessed on an indoor course. The total visual field score related significantly to the time taken to compete the course (R^2=0.30), and the number of errors made (R^2= 0.58).

A supplementary analysis of kinetic field data in the current study involved manually determining the average field extent from the kinetic isopter. These results were compared to the solid angle score that was automatically calculated. The kinetic average extent is similarly related to overall and mobility self-reported function when compared with the kinetic solid angle score, and account for a similar degree of variance in perceived mobility function. This suggests that either method of quantifying the kinetic field provides a good prediction of perceived function. Haymes et al., (1996) compared different existing methods of scoring the kinetic field, including methods described by Colenbrander et al., (1993) Marron & Bailey (1982), and Brown et al., (1986). They found the majority of methods of quantifying the kinetic field were similarly related to mobility performance suggesting these scores are largely interchangeable. Yanagisawa et al., (2011) combined monocular kinetic field plots, and used five methods of quantifying the field including the Visual Field Score, Functional Field Score, AMA guide, Esterman Disability Score, and solid angle determination. They found that while the Esterman Disability Score was the only score to significantly relate to self-reported function (R^2=0.12, p=0.02), the relationships were similarly poor for all methods.

Choy et al., (1986) also manually determined the average field extent, considering also the effect of internal scotomas. They used a III-4e stimulus target on a Goldmann perimeter, and related scores to self-reported function. Perceived function related similarly to the field extent including scotomas (R^2=0.40) and excluding scotomas (R^2=0.42), suggesting that no further information is provided by undertaking a more comprehensive, and time consuming kinetic assessment that assessed internal scotomas. A quick assessment of the field extent in the 12 principal meridians is sufficient to predict perceived function.

Custom tests were compared against existing field assessments. The Esterman was found to significantly relate to overall (R^2=0.40, p<0.001) and mobility self-reported function (R^2=0.46, p<0.001), reflecting other studies that suggest the Esterman test is a good predictor of visual function (Choy et al., 1986; Parrish et al., 1997; Fujita et al., 2008). The majority of studies that utilise this assessment however have reported weaker correlations (Turano et al., 1999; Viswanathan et al., 1999; Yanagiswara et al., 2001; Jampel et al., 2002a; 2002b; Nelson et al., 2003; Noe et al., 2003). Although, consistent with the current study, Choy et al., (1986) compared the binocular Esterman assessment's relationship with self-reported function with binocular kinetic tests and suggested that both assessments are similarly effective at visual disability estimation.

Integrated visual fields scores were manually calculated using the best location algorithm and provided a further existing assessment against which the custom test designs could be assessed. The relationship between visual field score and overall (R^2=0.32, p<0.001) and mobility self-reported function (R^2=0.38, p<0.001) remains significant, but weaker than that of the binocular measured fields assessments. In multiple regression analyses, although the IVF was selected as the most significant predictor of self-reported mobility function, the score accounted for a smaller proportion of variance in perceived function when compared with the four other visual field assessments, suggesting that all other binocular methods of visual field assessment were be more effective at predicting perceived function than the IVF (Figure 5.17). Black et al., (2011) also related IVF to visual function. Physical performance and self-reported activity level were combined to produce an overall functional status score. Greater visual impairment was associated with poorer functional status (R^2=0.29, p<0.05). A similar relationship was found when Aspinall et al., (2008) compared the IVF with perceived mobility function (R^2=0.26). Jampel et al., (2002b) compared the IVF to Esterman, and custom suprathreshold assessments and found that a global score derived from a combination of two monocular fields correlated better with patient assessment of vision than did the Esterman and four novel binocular visual field tests.

Crabb & Viswanathan (2004) assessed the visual field of 48 glaucoma patients using IVF and Esterman assessments, and determined perceived function of nine mobility tasks including "do you trip on things or have difficulty with stairs?" and "do you bump into things sometimes?". ROC analysis was used to compare the diagnostic precision of Esterman visual fields and IVF at selecting patients with a perceived difficulty with a visual task. As with the present study (AUC median Esterman: 0.79, IVF: 0.74), responses to the nine-item questionnaire could be predicted by both the IVF (AUC median=0.79) and the Esterman (AUC median 0.70). Three of the questions were found to have significantly different AUC indicating the superiority of IVF at predicting perceived mobility function. Four items on the questionnaire used in Crabb & Viswanathan's study were similar to the task questions used in the current analysis, and a comparison of AUC for these questions are provided in Table 5.17. In the current study, the Esterman was found to be significantly more effective than the IVF at predicting difficulty avoiding bumping into obstacles, and trouble with glare. There was no significant difference in the AUCs for the two other questions. This is contrary to the findings of Crabb & Viswanathan (2004) who found that while no significant difference in AUCs existed for all but one question, the IVF was a better indicator of difficulty avoiding tripping over obstacles. The difference in these areas could be due to differences in the wording of the questions, but may also be due to differences in the sample groups. The average Esterman score in the current study (56.4%) is less than the average score (86.7%) reported by Crabb & Viswanathan and would suggest a sample with greater degree of visual field loss.

	Crabb & Viswanathan, 2004		Current study	
	IVF	Esterman	IVF	Esterman
Avoiding tripping over obstacles	0.89*	0.78	0.67	0.65
Difficulty moving from light to dark area	0.77	0.70	0.71	0.73
Avoiding bumping into obstacles	0.74	0.72	0.73	0.81*
Trouble with glare	0.63	0.58	0.60	0.72*

Table 5.17 Comparison of areas under the curve for four items in the questionnaire used in the current study that were similar to the task questions used in Crabb & Viswanathan (2004).

As the complete set of results from the ROC analysis show, the IVF was not selected as a better diagnostic test when compared with any of the other four assessments for all 35 questionnaire items. Significant differences in the AUCs indicate the binocular threshold and binocular suprathreshold assessments are better than the IVF at predicting difficulty walking in familiar areas, walking in unfamiliar areas, walking at home, walking in crowded areas, avoiding bumping into knee height objects, and finding public toilets. The binocular threshold assessment is also better than the IVF at predicting difficulty avoiding bumping into people. All three custom tests and the Esterman assessment are better than the IVF at predicting difficulty avoiding bumping into waist height objects, and at predicting difficulty avoiding bumping into low lying objects. These results are contrary to those of Crabb & Viswanathan (2004) and Jampel et al., (2002a), and instead indicate the inferiority of IVF when compared to binocular assessments of the visual field out to 60-90 deg, using varying paradigms.

5.5 Conclusion

While all five visual fields assessments relate similarly to perceived function, the three custom tests, and the Esterman are shown to explain a greater degree of variance in self-reported mobility function in multiple regression analyses, and produce statistically significant greater AUCs in ROC analyses. A binocular visual field test that considers the peripheral 30-60 degrees of the field is effective for reflecting functional difficult, particularly in mobility related activities.

Chapter 6

Experiment 2: Visual Field Areas

6.1 Introduction

The association between visual fields and functional ability in individuals with visual impairment is well documented (Lovie-Kitchin et al., 1990; Gutierrez et al., 1997; Parrish et al., 1997; Noe et al., 2003; Crabb & Viswanathan, 2004; Asaoka et al., 2012; Tabrett & Latham 2012; Crabb et al., 2013; El-Gasim et al., 2013), and it has been demonstrated in previous chapters that both the central and peripheral areas are good predictors of perceived function. Results of the first experiment also indicate that the inferior visual field is a slightly stronger predictor of overall and mobility function than the superior field. In this chapter, the relationship between self-reported function and visual field areas is explored using the different test paradigms to determine which areas within the visual field, assessed using threshold, suprathreshold, and kinetic paradigms, are more important to reflect activities of daily living.

6.2 Methods

Data from Experiment 2, collected as outlined in Chapter 5, were evaluated. The outcome measures to which the visual field scores were related were the Dutch Activity Inventory to represent overall self-reported function and the Independent Mobility Questionnaire to represent self-reported mobility function as previously described.

The overall (0-60 deg) binocular static visual field data (binocular threshold, suprathreshold, and Esterman results) was first divided into central (0-30 deg) and peripheral (30+ deg) visual field areas, and all visual field data (from all five assessments) were divided into overall (0-80 deg) superior and inferior visual field areas (Figure 6.1). The mean thresholds (dB) (for binocular threshold and IVF data), and percentage of points seen (for binocular suprathreshold, and Esterman data), for these areas were calculated where appropriate and used for analysis. For binocular kinetic data, field extent (deg^2) was used. Mean thresholds, and percentage of points seen were also calculated for finer 10 degree annular divisions for the binocular threshold, binocular suprathreshold, Esterman, and IVF results. Descriptive statistics for all visual field areas are provided in Table 6.1.

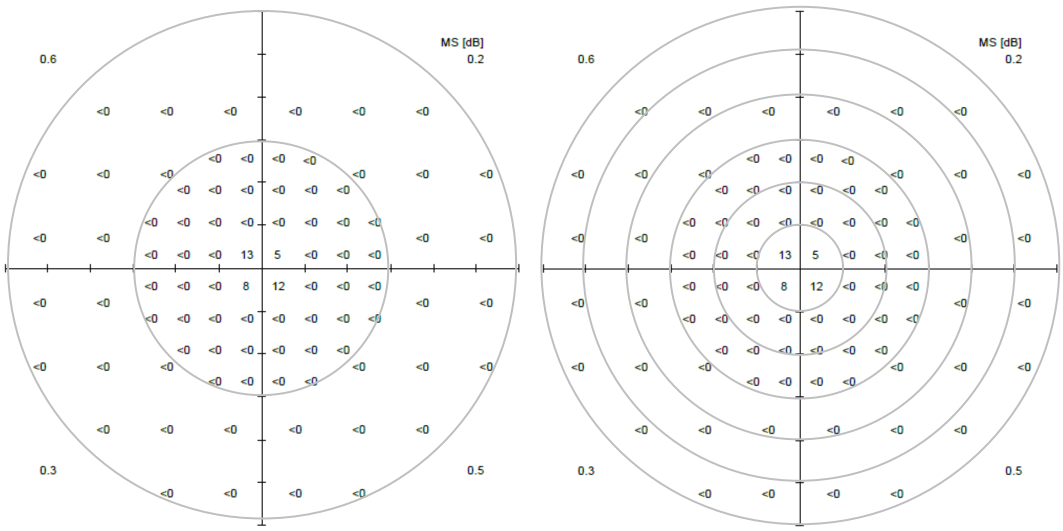


Figure 6.1 The visual field was divided into (a) central 0-30 degrees and peripheral 30-60 degrees, and (b) finer 10 degree divisions. The mean threshold in each of these visual field areas was calculated and used in analysis.

6.2.1 Analysis

Spearman's rho bivariate correlations were conducted to investigate the relationship between the visual field areas and self-reported visual function. To explore the unique variance explained by each predictor variable, visual field areas were entered into the regression model in a forward stepwise manner using an alpha of 0.05. Collinearity statistics were assessed to determine whether scores for different visual field areas were independent. As described in previous chapters, these measures included the tolerance and variance inflation factor statistics.

Similarly to the ROC analysis described in Chapter 3, the binary responses to the 35 task questions of the IMQ were used to compare different visual field areas, in order to evaluate how effective they were at selecting participants with perceived mobility difficulty.

6.3 Results

Results for each visual field are provided in Table 6.1. These are now considered further by comparing different regions of the visual field and self-reported function.

	Visual field area	Mean (±std)	Median (25% IQ-75% IQ))	Range
Binocular threshold (dB)	Central 0-30 deg	12.73(±1.35)	11.66(3.29-21.92)	0.45-28.96
	Peripheral 30-60 deg	8.14(±0.99)	7.24(0.92-15.00)	0.00-21.92
	Superior 0-60	10.16(±1.23)	6.78(1.60-18.48)	0.10-25.55
	Inferior 0-60	11.55(±1.22)	12.73(2.78-19.65)	0.13-25.65
Binocular suprathreshold (%)	Central 0-30 deg	58.58(±5.11)	63.46(25.00-98.08)	33.85-100.00
	Peripheral 30-60 deg	48.56(±5.34)	48.61(5.56-88.89)	0..00-97.22
	Superior 0-60	52.95(±5.46)	48.81(14.29-95.24)	0.00-1.00
	Inferior 0-60	55.87(±5.13)	56.43(19.57-91.30)	2.17-100.00
Binocular kinetic extent (deg)	Superior 0-60	37.08(±3.01)	41.05(19.00-53.91)	3.18-105.09
	Inferior 0-60	39.63(±2.96)	49.91(16.73-57.00)	3.17-60.00
	Horizontal extent	84.70(±5.53)	99.00(48.00-117.00)	11.00-120.00
	Vertical extent	67.94(±5.28)	82.00(31.00-101.00)	4.00-119.00
Esterman (%)	Central 0-30 deg	67.13(±4.87)	77.17(32.61-100.00)	0.00-100.00
	Peripheral 30-80 deg	54.41(±5.05)	56.08(20.27-87.84)	0.00-100.00
	Peripheral 30-60 deg	58.96(±5.50)	69.00(18.00-96.00)	0.00-100.00
	Superior 0-80	58.79(±4.94)	69.74(32.21-92.11)	0.00-100.00
	Inferior 0-80	59.73(±4.89)	67.07(30.49-91.46)	0.00-100.00
Integrated monocular threshold (dB)	Superior 0-24	14.78(±1.57)	15.87(3.54-25.54)	0.69-31.73
	Inferior 0-24	16.59(±1.57)	16.90(5.12-27.58)	0.27-32.19

Table 6.1 Descriptive statistics of the visual field scores. Higher scores indicate greater mean thresholds, and better visual fields.

6.3.1 Central vs peripheral

The central and peripheral visual field areas are similarly related to overall self-reported function for binocular threshold (R^2=0.39, p<0.001 and R^2=0.45, p<0.001), binocular suprathreshold (R^2=0.40, p<0.001 and R^2=0.37, p<0.001), and Esterman scores (R^2=0.33, p<0.001 and R^2=0.39, p<0.001). Both visual field areas are also similarly related to self-reported mobility function (Table 6.2).

	Visual field area	Overall D-AI score (R^2)	Mobility function (R^2)
Binocular threshold (dB)	Central 0-30 deg	0.39*	0.44*
	Peripheral 30-60 deg	0.45*	0.48*
	0-10 deg	0.26*	0.29*
	10-20 deg	0.36*	0.42*
	20-30 deg	0.36*	0.44*
	30-40 deg	0.41*	0.43*
	40-50 deg	0.42*	0.44*
	50-60 deg	0.45*	0.51*
Binocular suprathreshold (%)	Central 0-30 deg	0.40*	0.47*
	Peripheral 30-60 deg	0.37*	0.43*
	0-10 deg	0.16	0.21
	10-20 deg	0.38*	0.46*
	20-30 deg	0.36*	0.44*
	30-40 deg	0.36*	0.39*
	40-50 deg	0.36*	0.34*
	50-60 deg	0.41*	0.44*
Esterman (%)	Central 0-30 deg	0.33*	0.40*
	Peripheral 30-80 deg	0.39*	0.44*
	Peripheral 30-60 deg	0.36*	0.42*
	0-10 deg	0.12	0.22
	10-20 deg	0.30*	0.36*
	20-30 deg	0.36*	0.42*
	30-40 deg	0.30*	0.36*
	40-50 deg	0.33*	0.35*
	50-60 deg	0.36*	0.46*
	60-70 deg	0.45*	0.44*
	70-80 deg	0.23*	0.31*
Integrated monocular threshold (dB)	Overall 0-24 deg	0.33*	0.38*
	0-10 deg	0.29*	0.37*
	10-20 deg	0.32	0.38
	20-30 deg	0.33	0.40

Table 6.2 Bivariate analysis comparing the overall, central and peripheral visual field scores, and self-reported visual function overall, and mobility function. Non parametric 2-tailed Spearman's correlations coefficients are used (*$p<0.001$, all others $p\geq0.001$).

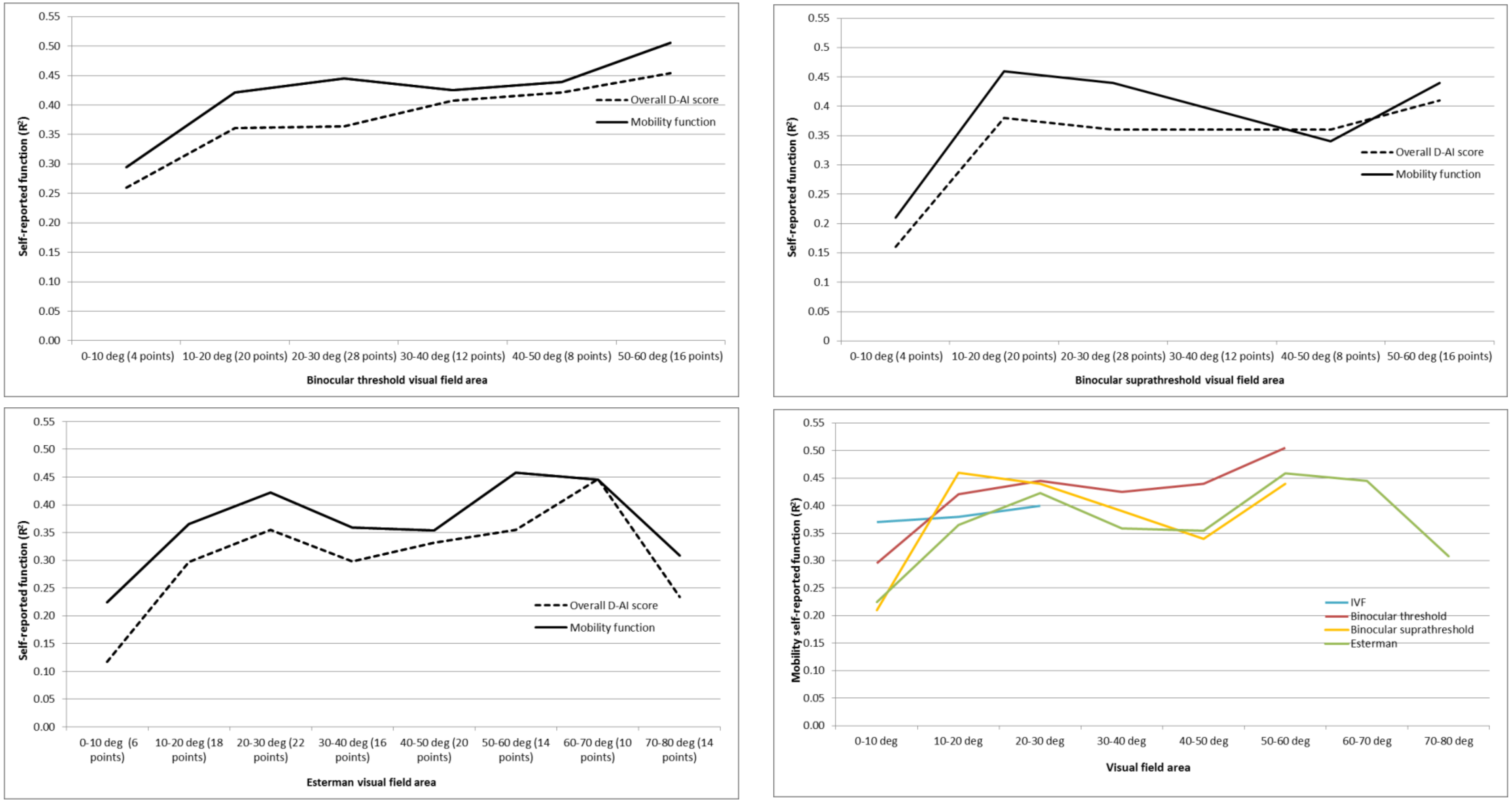


Figure 6.2 Graphical representations of the relationship between visual field areas and self-reported function for the different visual field assessments.

Analyses of the relationship between 10 degree bands of the visual field and self-reported function suggest that the while there may be a relationship between visual field extent and perceived function, the variation in this relationship with increasing eccentricity is subtle. As Table 6.3 demonstrates, the R^2 values for all four static visual field assessments suggest the central 10 degrees of the visual field is least effective at predicting self-reported function when compared with the visual field past 10 degrees eccentricity. As the plotted R^2 values in Figure 6.2 illustrate, the correlation between the visual field and function increases gradually with increasing eccentricity until between 10-30 degrees, and then plateaus or decreases slightly. A second peak in the R^2 value between 50-70 degrees is observed in all plots. While the relationship between the peripheral Esterman field score and self-reported function is similar when considering the peripheral visual field from 30 to 60 deg, or from 30 to 80 degrees, the peripheral 70-80 degrees of the Esterman field is more weakly correlated with overall (R^2=0.23, p<0.001) and mobility (R^2=0.31, p<0.001) function compared with other regions of the visual field. This can be seen in Figure 6.2 as a sharp decrease in the slope after 70 degree eccentricity. This would suggest that while there is a significant relationship between the visual field and self-reported function across the entire visual field, the mid peripheral region around 10-30 degrees, and the far periphery around 50-70 degrees are slightly better at predicting perceived function overall and with mobility tasks compared with other regions.

		B	**SE B**	**β**	**R^2 change**
Binocular threshold (dB)	**Overall D-AI score**				
	Constant	-1.51	0.36		
	Peripheral 30-6 deg threshold field	-0.15	0.03	-0.52***	0.45***
	VA	1.36	0.39	0.37***	0.12**
	R^2	0.57			
	Adjusted R^2	0.55			
	Mobility function				
	Constant	0.10	0.26		

	Peripheral 30-60 deg threshold field	-0.16	0.03	-0.69***	0.48***
	R^2	0.48			
	Adjusted R^2	0.46			
Binocular suprathreshold (%)	**Overall D-AI score**				
	Constant	1.22	0.63		
	Binocular CS	-1.69	0.47	-0.44	0.42***
	Peripheral 30-60 deg suprathreshold field	-0.02	0.01	-0.38	0.10**
	R^2	0.52			
	Adjusted R^2	0.50			
	Mobility function				
	Constant	0.48	0.35		
	Central 0-30 deg suprathreshold field	-0.03	0.01	-0.64***	0.41***
	R^2	0.41			
	Adjusted R^2	0.39			
Esterman (%)	**Overall D-AI score**				
	Constant	-1.35	0.40		
	Peripheral 30-80 deg Esterman	-0.03	0.01	-0.47***	0.42***
	Binocular VA	1.67	0.37	0.46***	0.14**
	R^2	0.56			
	Adjusted R^2	0.54			
	Mobility function				
	Constant	-0.05	0.35		
	Peripheral 30-80 deg Esterman	-0.03	0.01	-0.56***	0.40***
	Binocular VA	0.84	0.34	0.28*	0.07*
	R^2	0.47			
	Adjusted R^2	0.45			

Table 6.3 Results of stepwise regression analyses to determine which clinical visual function variables, including central and peripheral visual field scores, best represent overall self-reported function, and mobility function using the entire sample (n=52). (B= unstandardised regression coefficients, SE B= standard errors, β= standardised regression coefficients R^2 change= amount of additional variance by including predictors from sample, Adjusted R^2=

variance accounted for if derived from the population from which the sample was taken (Fields, 2005) (* $p < 0.05$, ** $p<0.01$, *** $p<0.001$).

Stepwise multiple regressions were conducted individually for each visual field assessment scores to investigate the degree of variance explained by the central and peripheral visual field areas. The central (0-30 deg) and peripheral (30-60 deg) binocular threshold visual field scores were entered in to the regression along with binocular VA and binocular CS. The peripheral (30-60 deg) visual field was selected as the primary predictor of overall self-reported function accounting for 45% of variance in the results, increasing to 57% when combined with binocular VA. The peripheral visual field was selected as the sole predictor of self-reported mobility function, explaining 48% of the variance in the results. The same clinical predictors (binocular VA and binocular CS) were entered into a further two stepwise multiple regression analyses along with the central (0-30 deg) and peripheral (30-60 deg) visual field scores for binocular suprathreshold and the central (0-30 deg) and peripheral (30-80 deg) Esterman field scores. Complete results are provided in Table 6.3. The peripheral (30-80 deg) Esterman score was selected as the primary predictor of overall and mobility related function, explaining 42% and 40% of the variance in results respectively, however in another multiple regression analysis with the binocular suprathreshold field scores binocular CS was selected as the primary predictor of overall self-reported function, and the central (0-30 deg) binocular suprathreshold field score was selected as the primary predictor of mobility function, explaining 42% and 41% of variance in results respectively.

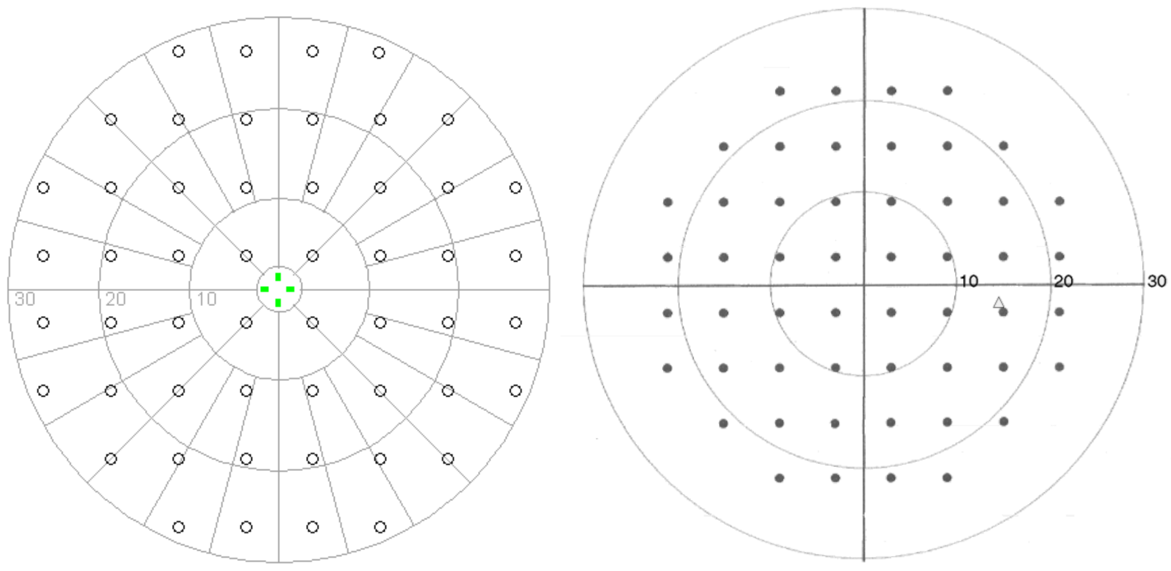


Figure 6.3 (a) Test point patterns showing the point distribution of the central 0-30 degrees assessing in the binocular threshold (and suprathreshold) assessment (b) The HFA 24-2 pattern with 2 nasal points removed used for to construct the IVF.

Both the binocular threshold and IVF tests assessed the central 0-30 degrees of the visual field using a threshold paradigm (Figure 6.3). The difference in the relationship between the central (0-30 deg) visual field and self-reported function between these two assessments was explored. A summary of differences between the two assessments are provided in Table 6.4. The central (0-30 deg) binocular threshold visual field score was highly correlated with the IVF score (R^2=0.89, p<0.001). Although both the central (0-30 deg) binocular threshold field, and the IVF score were also significantly correlated with overall function (R^2=0.39, p<0.001 and R^2=0.33, p<0.001 respectively) and mobility function (R^2=0.44, p<0.001 and R^2=0.38, p<0.001 respectively), there is a slightly stronger relationship between the central field assessed binocularly than the IVF score, suggesting the central binocular threshold field score, with a wider point spacing and therefore fewer points in the central 10 deg, may explain a little more of the variance in self-reported function when compared with the IVF assessment which has a higher density of points in the central 10 deg, but a reduced density (and reduced extent) of points beyond 20 degrees in the visual field.

	Binocular threshold central visual field	**Integrated monocular field**
Perimeter	Octopus 900	HFA
Measurement	Binocular	Best location
Threshold technique	Low Vision	SITA Fast
Point spacing	7.5 deg	6 deg
Total number of test points	52	52
Number of points in 0-10 deg	4	12
Number of points 10-20 deg	20	20
Number of points 20-30 deg	28	20
Maximum eccentricity of points tested	25 deg	21 deg

Table 6.4 Table summarising the differences between the monocular and binocular threshold visual field assessments.

6.3.2 Superior vs inferior

Overall (0-60 deg) superior and inferior visual field areas are both significantly related to overall self-reported function for all field paradigms with a tendency for the inferior field to be more strongly correlated with function. This is similar to the relationship between these visual field areas and self-reported mobility function (Table 6.5). There does not appear to be a huge variation in these relationships with increasing eccentricity. Although the relationship between visual field and overall and mobility related function is slightly stronger for the peripheral inferior visual field compared with other regions for all static visual field assessments that consider the field past 30 degrees, the correlations are similar across both regions.

Visual field assessment	Visual field area	Overall D-AI score (R^2)	Mobility function (R^2)
Binocular threshold	Overall (0-60 deg) superior	0.34*	0.43*
	Overall (0-60 deg) inferior	0.43*	0.46*
	Central (0-30 deg) superior	0.34*	0.42*
	Central (0-30 deg) inferior	0.40*	0.43*
	Peripheral (30-60 deg) superior	0.36*	0.41*
	Peripheral (30-60) inferior	0.46*	0.46*
Binocular suprathreshold	Overall (0-60 deg) superior	0.35*	0.44*
	Overall (0-60 deg) inferior	0.42*	0.46*
	Central (0-30 deg) superior	0.36*	0.46*
	Central (0-30 deg) inferior	0.39*	0.44*
	Peripheral (30-60 deg) superior	0.33*	0.36*
	Peripheral (30-60) inferior	0.39*	0.41*
Binocular kinetic extent (deg)	Superior extent	0.29*	0.35*
	Inferior extent	0.50*	0.52*
	Horizontal extent	0.43*	0.52*
	Vertical extent	0.26*	0.35*
Esterman	Overall (0-80 deg) superior	0.34*	0.43*
	Overall (0-80 deg) inferior	0.40*	0.43*
	Central (0-30 deg) superior	0.34*	0.43*
	Central (0-30 deg) inferior	0.39*	0.46*
	Peripheral (30-80 deg) superior	0.37*	0.45*
	Peripheral (30-80) inferior	0.39*	0.44*
Integrated monocular threshold (dB)	Superior (0-24 deg)	0.23*	0.33*
	Inferior (0-24 deg)	0.36*	0.39*

Table 6.5 Bivariate analysis comparing the overall, central and peripheral superior and inferior visual field scores, and self-reported visual function overall, and mobility function. Non parametric 2-tailed Spearman's correlations coefficients are used (*$p<0.001$).

A series of stepwise multiple regression analyses were conducted individually for each visual field assessment scores to investigate the variance in self-reported function that is explained by the overall (0-60 deg) superior and inferior visual field. The overall (0-60 degrees for binocular threshold and suprathreshold, 0-80 for Esterman, 0-24 degrees for IVF) superior and inferior visual field scores were entered in separate regression analysis along with binocular VA, and binocular CS. The inferior visual field was selected as the primary predictor of both overall and self-reported function for all visual field assessment scores, explaining between 38% and 43% of the variance in the results. The inferior visual field was the only predictor of self-reported mobility selected for binocular threshold and IVF scores. Binocular VA was selected as a secondary predictor in regression models for other visual field scores accounting for between 5% and 8% of variance in overall and mobility function. Complete results of these analyses are provided in Table 6.6.

		B	SE B	β	R^2 change
Binocular threshold (dB)	**Overall D-AI score**				
	Constant	-1.40	0.40		
	Inferior threshold field	-0.11	0.03	-0.49***	0.43***
	Binocular VA	1.37	0.40	0.38**	0.11**
	R^2	0.54			
	Adjusted R^2	0.52			
	Mobility function				
	Constant	0.21	0.30		
	Inferior threshold field	-0.12	0.02	-0.65***	0.42***
	R^2	0.42			
	Adjusted R^2	0.41			
Binocular suprathreshold (%)	**Overall D-AI score**				
	Constant	1.44	0.61		
	Binocular CS	-1.65	0.46	-0.42**	0.42***
	Inferior suprathreshold field	-0.02	0.01	-0.42**	0.12***
	R^2	0.54			
	Adjusted R^2	0.52			
	Mobility function				
	Constant	-0.03	0.39		
	Inferior suprathreshold field	-0.03	0.01	-0.55***	0.40***
	Binocular VA	0.71	0.35	0.23**	0.05*
	R^2	0.45			
	Adjusted R^2	0.42			

Binocular kinetic extent (deg)	**Overall D-AI score**				
	Constant	-0.97	0.46		
	Inferior kinetic field extent	-0.05	0.01	-0.48***	0.42***
	Binocular VA	1.68	0.36	0.46***	0.14**
	R^2	0.56			
	Adjusted R^2	0.54			
	Mobility function				
	Constant	0.21	0.43		
	Inferior kinetic field extent	-0.04	0.01	-0.54***	0.38***
	Binocular VA	0.88	0.34	0.29*	0.08**
	R^2	0.45			
	Adjusted R^2	0.43			
Esterman (%)	**Overall D-AI score**				
	Constant	1.61	0.62		
	Binocular CS	-1.69	0.46	-0.44***	0.42***
	Inferior Esterman	-0.02	0.01	-0.40***	0.11**
	R^2	0.53			
	Adjusted R^2	0.51			
	Mobility function				
	Constant	0.18	0.40		
	Inferior Esterman	-0.03	0.01	-0.57***	0.42***
	Binocular VA	0.75	0.34	0.25*	0.05*
	R^2	0.47			
	Adjusted R^2	0.45			
Integrated monocular threshold (dB)	**Overall D-AI score**				
	Constant	1.23	0.66		
	Binocular CS	-1.73	0.53	-0.45***	0.42***
	Inferior IVF	-0.06	0.02	-0.31*	0.06*
	R^2	0.48			
	Adjusted R^2	0.45			
	Mobility function				
	Constant	0.29	0.34		
	Inferior IVF	-0.09	0.02	-0.61***	0.38***
	R^2	0.38			
	Adjusted R^2	0.36			

Table 6.6 Results of stepwise regression analyses to determine which clinic visual function variables, including superior and inferior visual field scores, best represent overall self-reported function, and mobility function using the entire sample (n=52). (B= unstandardised regression coefficients, SE B= standard errors, β= standardised regression coefficients R^2 change= amount of additional variance by including predictors from sample, Adjusted R^2= variance accounted

for if derived from the population from which the sample was taken (Fields, 2005) (* $p< 0.05$, ** $p<0.01$, *** $p<0.001$).

6.3.3 ROC analysis

The areas under the ROC curves for the central and peripheral, and superior and inferior visual field areas suggest all regions are generally good indicators of self-reported function in mobility tasks (Table 6.7). Areas under the curve that are significantly different from 0.5 at the 95% confidence interval are highlighted in Table 6.7.

	Visual field variable	**Central AUC**	**Peripheral AUC**	**Superior AUC**	**Inferior AUC**
Walking in familiar areas	Binocular threshold (dB)	0.75(±0.09)*	0.80(±0.07)*	0.77(±0.08)*	0.77(±0.08)*
	Binocular suprathreshold (%)	0.78(±0.08)*	0.78(±0.09)*	0.79(±0.08)*	0.79(±0.08)*
	Binocular kinetic solid angle (deg^2)			0.76(±0.09)*	0.78(±0.08)*
	Esterman (%)	0.74(±0.09)*	0.78(±0.09)*	0.78(±0.08)	0.76(±0.09)*
	Integrated visual field (dB)			0.72(±0.09)*	0.71(±0.09)*
Walking in unfamiliar areas	Binocular threshold (dB)	0.80(±0.07)*	0.83(±0.06)*	0.79(±0.07)*	0.82(±0.07)*
	Binocular suprathreshold (%)	0.83(±0.06)*	0.83(±0.06)*	0.82(±0.06)*	0.83(±0.06)*
	Binocular kinetic solid angle (deg^2)			0.77(±0.07)*	0.85(±0.06)*
	Esterman (%)	0.77(±0.07)*	0.81(±0.06)*	0.80(±0.07)*	0.79(±0.07)*
	Integrated visual field (dB)			0.74(±0.08)*	0.73(±0.07)*
Moving about in the home	Binocular threshold (dB)	0.75(±0.08)*	0.82(±0.07)*	0.73(±0.08)*	0.80(±0.07)*
	Binocular suprathreshold (%)	0.80(±0.07)*	0.83(±0.07)*	0.79(±0.07)*	0.82(±0.06)*
	Binocular kinetic solid angle (deg^2)			0.80(±0.07)*	0.82(±0.06)*
	Esterman (%)	0.78(±0.07)*	0.81(±0.09)*	0.77(±0.07)*	0.80(±0.08)*
	Integrated visual field (dB)			0.68(±0.08)	0.72(±0.08)*

Moving about at work	Binocular threshold (dB)	0.92(±0.06)*	0.98(±0.00)*	0.87(±0.08)*	0.92(±0.06)*
	Binocular suprathreshold (%)	0.97(±0.03)*	0.97(±0.03)*	0.94(±0.05)*	0.97(±0.03)*
	Binocular kinetic solid angle (deg^2)			0.95(±0.05)*	0.90(±0.08)*
	Esterman (%)	0.95(±0.05)*	0.95(±0.05)*	0.93(±0.06)*	0.97(±0.03)*
	Integrated visual field (dB)			0.88(±0.08)*	0.88(±0.07)*
Moving about in the classroom					
Moving about in stores	Binocular threshold (dB)	0.81(±0.06)*	0.85(±0.06)*	0.80(±0.07)*	0.85(±0.06)*
	Binocular suprathreshold (%)	0.84(±0.06)*	0.83(±0.06)*	0.81(±0.06)*	0.87(±0.05)*
	Binocular kinetic solid angle (deg^2)			0.75(±0.08)*	0.88(±0.05)*
	Esterman (%)	0.83(±0.06)*	0.86(±0.05)*	0.81(±0.06)*	0.87(±0.05)*
	Integrated visual field (dB)			0.75(±0.07)*	0.81(±0.07)*
Moving about in outdoors	Binocular threshold (dB)	0.85(±0.06)*	0.86(±0.05)*	0.83(±0.06)*	0.86(±0.06)*
	Binocular suprathreshold (%)	0.87(±0.05)*	0.85(±0.06)*	0.84(±0.06)*	0.86(±0.05)*
	Binocular kinetic solid angle (deg^2)			0.76(±0.08)*	0.83(±0.06)*
	Esterman (%)	085.(±0.06)*	0.83(±0.06)*	0.82(±0.06)*	0.83(±0.07)*
	Integrated visual field (dB)			0.80(±0.07)*	0.87(±0.05)*
Moving about in crowded situations	Binocular threshold (dB)	0.87(±0.06)*	0.89(±0.05)*	0.86(±0.06)*	0.89(±0.05)*
	Binocular suprathreshold (%)	0.90(±0.05)*	0.90(±0.05)*	0.89(±0.05)*	0.90(±0.04)*
	Binocular kinetic solid angle (deg^2)			0.83(±0.06)*	0.94(±0.03)*
	Esterman (%)	0.88(±0.05)*	0.89(±0.05)*	0.87(±0.05)*	0.88(±0.05)*
	Integrated visual field (dB)			0.82(±0.07)*	0.81(±0.07)*
Walking at night	Binocular threshold (dB)	0.87(±0.06)*	0.89(±0.05)*	0.89(±0.05)*	0.86(±0.06)*
	Binocular suprathreshold (%)	0.88(±0.05)*	0.57(±0.06)*	0.88(±0.06)*	0.87(±0.05)*
	Binocular kinetic solid angle (deg^2)			0.88(±0.06)*	0.87(±0.05)*
	Esterman (%)	0.87(±0.05)*	0.89(±0.05)*	0.89(±0.05)*	0.89(±0.05)*
	Integrated visual field (dB)			0.88(±0.05)*	0.85(±0.06)*
Using public transport	Binocular threshold (dB)	0.77(±0.07)*	0.82(±0.06)*	0.75(±0.07)*	0.79(±0.07)*
	Binocular suprathreshold (%)	0.78(±0.07)*	0.79(±0.07)*	0.77(±0.07)*	0.81(±0.06)*

	Binocular kinetic solid angle (deg^2)			0.75(±0.08)*	0.79(±0.07)*
	Esterman (%)	0.72(±0.08)*	0.77(±0.07)*	0.74(±0.07)*	0.75(±0.08)*
	Integrated visual field (dB)			0.69(±0.08)*	0.77(±0.07)*
Detecting ascending stairwells	Binocular threshold (dB)	0.72(±0.08)*	0.75(±0.07)*	0.76(±0.07)*	0.70(±0.08)*
	Binocular suprathreshold (%)	0.74(±0.08)*	0.72(±0.08)*	0.75(±0.07)*	0.71(±0.08)*
	Binocular kinetic solid angle (deg^2)			0.70(±0.08)*	0.72(±0.08)*
	Esterman (%)	0.76(±0.07)*	0.75(±0.07)*	0.78(±0.07)*	0.72(±0.08)*
	Integrated visual field (dB)			0.74(±0.07)*	0.68(±0.08)*
Detecting descending stairwells	Binocular threshold (dB)	0.76(±0.08)*	0.74(±0.08)*	0.77(±0.08)*	0.73(±0.08)*
	Binocular suprathreshold (%)	0.78(±0.08)*	0.75(±0.08)*	0.78(±0.07)*	0.76(±0.08)*
	Binocular kinetic solid angle (deg^2)			0.69(±0.09)*	0.72(±0.08)*
	Esterman (%)	0.78(±0.07)*	0.70(±0.08)*	0.75(±0.08)*	0.71(±0.08)*
	Integrated visual field (dB)			0.72(±0.08)*	0.71(±0.08)*
Walking up steps	Binocular threshold (dB)	0.59(±0.08)	0.61(±0.08)	0.63(±0.08)	0.59(±0.08)
	Binocular suprathreshold (%)	0.63(±0.08)	0.58(±0.08)	0.62(±0.08)	0.58(±0.08)
	Binocular kinetic solid angle (deg^2)			0.58(±0.08)	0.65(±0.08)
	Esterman (%)	0.62(±0.08)	0.63(±0.08)	0.64(±0.08)	0.60(±0.08)
	Integrated visual field (dB)			0.59(±0.08)	0.56(±0.08)
Walking down steps	Binocular threshold (dB)	0.77(±0.08)*	0.76(±0.08)*	0.78(±0.08)*	0.75(±0.08)*
	Binocular suprathreshold (%)	0.77(±0.08)*	0.72(±0.08)*	0.77(±0.07)*	0.72(±0.08)*
	Binocular kinetic solid angle (deg^2)			0.68(±0.08)*	0.69(±0.08)*
	Esterman (%)	0.76(±0.07)*	0.69(±0.08)*	0.75(±0.08)*	0.69(±0.08)*
	Integrated visual field (dB)			0.73(±0.08)*	0.72(±0.08)*
Stepping onto curbs	Binocular threshold (dB)	0.72(±0.07)*	0.73(±0.07)*	0.72(±0.07)*	0.73(±0.07)*
	Binocular suprathreshold (%)	0.73(±0.07)*	0.67(±0.08)*	0.71(±0.07)*	0.69(±0.08)*
	Binocular kinetic solid angle (deg^2)			0.69(±0.08)*	0.74(±0.07)*
	Esterman (%)	0.73(±0.07)*	0.69(±0.08)*	0.71(±0.07)*	0.71(±0.07)*
	Integrated visual field (dB)			0.70(±0.08)*	0.71(±0.07)*
Stepping off curbs	Binocular threshold (dB)	0.74(±0.07)*	0.70(±0.08)*	0.72(±0.08)*	0.72(±0.08)*

	Binocular suprathreshold (%)	0.74(±0.07)*	0.71(±0.08)*	0.71(±0.08)*	0.73(±0.07)*
	Binocular kinetic solid angle (deg^2)			0.67(±0.08)*	0.74(±0.07)*
	Esterman (%)	0.73(±0.07)*	0.65(±0.08)*	0.69(±0.08)*	0.6(8±0.08)
	Integrated visual field (dB)			0.68(±0.08)*	0.71(±0.07)*
Walking through doorways	Binocular threshold (dB)	0.81(±0.06)*	0.79(±0.06)*	0.79(±0.07)*	0.81(±0.06)*
	Binocular suprathreshold (%)	0.82(±0.06)*	0.76(±0.07)*	0.79(±0.07)*	0.80(±0.07)*
	Binocular kinetic solid angle (deg^2)			0.75(±0.08)*	0.85(±0.05)*
	Esterman (%)	0.82(±0.06)*	0.79(±0.07)*	0.79(±0.07)*	0.80(±0.07)*
	Integrated visual field (dB)			0.76(±0.07)*	0.79(±0.07)*
Walking in high-glare areas	Binocular threshold (dB)	0.68(±0.12)	0.73(±0.11)*	0.72(±0.10)	0.69(±0.12)
	Binocular suprathreshold (%)	0.60(±0.10)	0.73(±0.11)*	0.67(±0.09)	0.72(±0.11)
	Binocular kinetic solid angle (deg^2)			0.78(±0.09)*	0.83(±0.90)*
	Esterman (%)	0.70(±0.10)	0.82(±0.09)*	0.76(±0.09)*	0.77(±0.10)*
	Integrated visual field (dB)			0.69(±0.10)	0.65(±0.11)
Adjusting to lighting changes during the day: Indoor to outdoor	Binocular threshold (dB)	0.72(±0.08)*	0.74(±0.08)*	0.74(±0.08)*	0.71(±0.08)*
	Binocular suprathreshold (%)	0.74(±0.08)*	0.79(±0.08)*	0.74(±0.07)*	0.76(±0.08)*
	Binocular kinetic solid angle (deg^2)			0.75(±0.08)*	0.71(±0.08)*
	Esterman (%)	0.68(±0.08)	0.76(±0.07)*	0.75(±0.07)*	0.71(±0.08)*
	Integrated visual field (dB)			0.74(±0.08)*	0.68(±0.09)*
Adjusting to lighting changes during the day: Outdoor to indoor	Binocular threshold (dB)	0.82(±0.07)*	0.81(±0.07)*	0.84(±0.06)*	0.78(±0.07)*
	Binocular suprathreshold (%)	0.82(±0.07)*	0.81(±0.07)*	0.81(±0.06)*	0.80(±0.07)*
	Binocular kinetic solid angle (deg^2)			0.75(±0.07)*	0.84(±0.08)*
	Esterman (%)	0.78(±0.08)*	0.76(±0.07)*	0.80(±0.07)*	0.75(±0.08)*
	Integrated visual field (dB)			0.83(±0.07)*	0.82(±0.08)*
Adjusting to lighting changes at night: Indoor to streetlights	Binocular threshold (dB)	0.81(±0.08)*	0.79(±0.08)*	0.82(±0.07)*	0.77(±0.08)*
	Binocular suprathreshold (%)	0.77(±0.07)*	0.81(±0.07)*	0.76(±0.07)*	0.81(±0.08)*
	Binocular kinetic solid angle (deg^2)			0.76(±0.08)*	0.74(±0.09)*
	Esterman (%)	0.82(±0.08)*	0.79(±0.07)*	0.79(±0.08)*	0.80(±0.08)*
	Integrated visual field (dB)			0.81(±0.08)*	0.82(±0.08)*

Adjusting to lighting changes at night: Streetlights to indoor	Binocular threshold (dB)	0.67(±0.08)*	0.70(±0.08)*	0.67(±0.08)*	0.69(±0.08)*
	Binocular suprathreshold (%)	0.67(±0.08)*	0.68(±0.08)*	0.67(±0.08)*	0.68(±0.08)*
	Binocular kinetic solid angle (deg^2)			0.66(±0.08)	0.68(±0.08)*
	Esterman (%)	0.65(±0.08)	0.69(±0.08)*	0.67(±0.08)*	0.67(±0.08)*
	Integrated visual field (dB)			0.66(±0.08)	0.68(±0.08)*
Walking in dimly lit indoor areas	Binocular threshold (dB)	0.70(±0.10)	0.73(±0.10)*	0.72(±0.10)*	0.68(±0.10)
	Binocular suprathreshold (%)	0.65(±0.09)	0.69(±0.10)	0.66(±0.09)	0.69(±0.10)
	Binocular kinetic solid angle (deg^2)			0.62(±0.10)	0.66(±0.11)
	Esterman (%)	0.64(±0.10)	0.68(±0.10)	0.68(±0.10)	0.69(±0.10)
	Integrated visual field (dB)			0.66(±0.11)	0.69(±0.10)
Being aware of another person's presence	Binocular threshold (dB)	0.85(±0.60)*	0.87(±0.05)*	0.86(±0.05)*	0.85(±0.06)*
	Binocular suprathreshold (%)	0.84(±0.06)*	0.85(±0.06)*	0.85(±0.05)*	0.85(±0.06)*
	Binocular kinetic solid angle (deg^2)			0.79(±0.08)*	0.81(±0.08)*
	Esterman (%)	0.81(±0.06)*	0.87(±0.05)*	0.87(±0.05)*	0.84(±0.06)*
	Integrated visual field (dB)			0.84(±0.06)*	0.82(±0.07)*
Avoiding bumping into: People	Binocular threshold (dB)	0.80(±0.06)*	0.85(±0.05)*	0.83(±0.06)*	0.83(±0.06)*
	Binocular suprathreshold (%)	0.82(±0.06)*	0.81(±0.06)*	0.83(±0.06)*	0.80(±0.06)*
	Binocular kinetic solid angle (deg^2)			0.81(±0.06)*	0.88(±0.05)*
	Esterman (%)	0.81(±0.06)*	0.85(±0.05)*	0.83(±0.06)*	0.83(±0.06)*
	Integrated visual field (dB)			0.77(±0.07)*	0.78(±0.07)*
Avoiding bumping into: Walls	Binocular threshold (dB)	0.71(±0.08)*	0.73(±0.07)*	0.73(±0.07)*	0.70(±0.07)*
	Binocular suprathreshold (%)	0.73(±0.07)*	0.74(±0.07)*	0.73(±0.07)*	0.70(±0.07)*
	Binocular kinetic solid angle (deg^2)			0.69(±0.08)*	0.78(±0.06)*
	Esterman (%)	0.70(±0.08)*	0.76(±0.07)*	0.74(±0.07)*	0.73(±0.07)*
	Integrated visual field (dB)			0.68(±0.08)*	0.70(±0.08)*
Avoiding bumping into: Head-height objects	Binocular threshold (dB)	0.83(±0.07)*	0.86(±0.07)*	0.87(±0.06)*	0.82(±0.07)*
	Binocular suprathreshold (%)	0.79(±0.07)*	0.83(±0.07)*	0.82(±0.07)*	0.81(±0.08)*
	Binocular kinetic solid angle (deg^2)			0.85(±0.07)*	0.84(±0.07)*
	Esterman (%)	0.78(±0.07)*	0.82(±0.07)*	0.84(±0.07)*	0.81(±0.07)*

	Integrated visual field (dB)			0.84(±0.07)*	0.83(±0.07)*
Avoiding bumping into: Shoulder-height objects	Binocular threshold (dB)	0.78(±0.07)*	0.80(±0.07)*	0.78(±0.07)*	0.78(±0.07)*
	Binocular suprathreshold (%)	0.79(±0.07)*	0.79(±0.07)*	0.79(±0.06)*	0.78(±0.07)*
	Binocular kinetic solid angle (deg^2)			0.81(±0.06)*	0.81(±0.06)*
	Esterman (%)	0.75(±0.07)*	0.80(±0.06)*	0.80(±0.06)*	0.78(±0.07)*
	Integrated visual field (dB)			0.76(±0.07)*	0.74(±0.07)*
Avoiding bumping into: Waist-height objects	Binocular threshold (dB)	0.75(±0.07)*	0.81(±0.06)*	0.72(±0.07)*	0.81(±0.06)*
	Binocular suprathreshold (%)	0.80(±0.06)*	0.81(±0.06)*	0.76(±0.07)*	0.85(±0.05)*
	Binocular kinetic solid angle (deg^2)			0.78(±0.08)*	0.86(±0.05)*
	Esterman (%)	0.76(±0.07)*	0.83(±0.06)*	0.76(±0.07)*	0.83(±0.06)*
	Integrated visual field (dB)			0.68(±0.08)*	0.75(±0.07)*
Avoiding bumping into: Knee-height objects	Binocular threshold (dB)	0.79(±0.06)*	0.85(±0.05)*	0.75(±0.04)*	0.84(±0.05)*
	Binocular suprathreshold (%)	0.83(±0.06)*	0.82(±0.06)*	0.78(±0.07)*	0.87(±0.05)*
	Binocular kinetic solid angle (deg^2)			0.69(±0.08)*	0.87(±0.05)*
	Esterman (%)	0.78(±0.06)*	0.85(±0.05)*	0.77(±0.07)*	0.85(±0.05)*
	Integrated visual field (dB)			0.69(±0.08)*	0.80(±0.06)*
Avoiding bumping into: Low-lying objects	Binocular threshold (dB)	0.77(±0.07)*	0.82(±0.06)*	0.75(±0.07)*	0.82(±0.06)*
	Binocular suprathreshold (%)	0.79(±0.07)*	0.77(±0.07)*	0.75(±0.07)*	0.82(±0.06)*
	Binocular kinetic solid angle (deg^2)			0.72(±0.08)*	0.86(±0.06)*
	Esterman (%)	0.73(±0.07)*	0.80(±0.07)*	0.76(±0.07)*	0.80(±0.07)*
	Integrated visual field (dB)			0.67(±0.08)*	0.74(±0.07)*
Avoiding tripping over uneven travel surfaces	Binocular threshold (dB)	0.68(±0.11)	0.62(±0.11)	0.6/(±0.10)	0.64(±0.11)
	Binocular suprathreshold (%)	0.68(±0.11)	0.63(±0.10)	0.66(±0.10)	0.65(±0.11)
	Binocular kinetic solid angle (deg^2)			0.67(±0.11)	0.68(±0.11)
	Esterman (%)	0.66(±0.11)	0.58(±0.10)	0.61(±0.10)	0.60(±0.10)
	Integrated visual field (dB)			0.64(±0.11)	0.65(±0.11)
Moving around in social gatherings	Binocular threshold (dB)	0.85(±0.57)*	0.89(±0.05)*	0.84(±0.06)*	0.87(±0.05)*
	Binocular suprathreshold (%)	0.87(±0.05)*	0.85(±0.06)*	0.85(±0.06)*	0.86(±0.05)*

	Binocular kinetic solid angle (deg^2)			0.78(±0.07)*	0.85(±0.06)*
	Esterman (%)	0.83(±0.06)*	0.86(±0.05)*	0.85(±0.06)*	0.84(±0.06)*
	Integrated visual field (dB)			0.81(±0.06)*	0.83(±0.06)*
Finding restrooms in public places	Binocular threshold (dB)	0.81(±0.06)*	0.87(±0.05)*	0.80(±0.06)*	0.84(±0.06)*
	Binocular suprathreshold (%)	0.83(±0.60)*	0.83(±0.07)*	0.82(±0.06)*	0.85(±0.06)*
	Binocular kinetic solid angle (deg^2)			0.81(±0.07)*	0.85(±0.05)*
	Esterman (%)	0.76(±0.07)*	0.83(±0.06)*	0.80(±0.06)*	0.81(±0.07)*
	Integrated visual field (dB)			0.74(±0.07)*	0.81(±0.06)*
Seeing cars at intersections	Binocular threshold (dB)	0.75(±0.08)*	0.78(±0.07)*	0.76(±0.08)*	0.76(±0.08)*
	Binocular suprathreshold (%)	0.76(±0.07)*	0.75(±0.07)*	0.77(±0.07)*	0.74(±0.08)*
	Binocular kinetic solid angle (deg^2)			0.75(±0.08)*	0.80(±0.07)*
	Esterman (%)	0.74(±0.07)*	0.79(±0.07)*	0.78(±0.07)*	0.76(±0.07)*
	Integrated visual field (dB)			0.73(±0.08)*	0.73(±0.08)*

Table 6.7 Receiver operating characteristics (ROC) areas under the curves (AUC) describing the relative performance of the difference visual field areas in predicting self-reported function in mobility related tasks. There was not sufficient responses to the task "moving about in the classroom" to determine these statistics. *indicates AUCs that are significantly ($p \leq 0.05$) different from 0.50.

Statistically significant differences between areas under the ROC curves were determined to establish if a visual field area was better at predicting perceived mobility function (Table 6.8). The peripheral (30-60 deg) binocular threshold field score was found to be significantly better than the central (0-30 deg) score at predicting difficulty with avoiding bumping into waist height objects ($z=2.17$, $p=0.030$), and avoiding bumping into knee height objects ($z=2.05$, p=0.040). No statistically significant differences between the central and peripheral field regions' AUCs were found for other visual field assessments.

The inferior binocular kinetic extent was found to be significantly better than the superior extent at predicting difficulty moving about in stores (z=2.18, p=0.029), avoiding bumping into waist height objects (z=2.47, p=0.014), avoiding bumping into knee height objects (z=3.38, p<0.001), and avoiding bumping into low lying objects (z=2.59, p=0.010). The inferior binocular threshold visual field was found to be significantly more effective than the superior visual field at correctly identifying participants who reported difficulty avoiding bumping into waist height objects (z=2.15, p=0.032), and avoiding bumping into knee height objects (z=2.03, p=0.043). The inferior IVF score was better was significantly better than the superior score as predicting difficulty avoiding bumping into low lying objects (z=2.59, p=0.010). The AUCs for the superior visual field scores was not significantly greater than the inferior field scores for any of the visual field assessments.

Mobility task	Visual field tests being compared	Difference between areas (±std)	z statistic	Significance value
Moving about in stores	Binocular inferior kinetic extent* Binocular superior kinetic extent	0.13(±0.06)	2.18	0.029
Avoid bumping into: Waist height objects	Binocular peripheral threshold field* Binocular central threshold field	0.06(±0.03)	2.17	0.030
Avoid bumping into: Waist height objects	Binocular inferior threshold field* Binocular superior threshold field	0.09(±0.04)	2.15	0.032

Avoid bumping into: Waist height objects	Binocular inferior kinetic extent* Binocular superior kinetic extent	0.13(±0.05)	2.47	0.014
Avoid bumping into: Knee height objects	Binocular peripheral threshold field* Binocular central threshold field	0.06(±0.03)	2.05	0.040
Avoid bumping into: Knee height objects	Binocular inferior threshold field* Binocular superior threshold field	0.09(±0.05)	2.03	0.043
Avoid bumping into: Knee height objects	Binocular inferior kinetic extent* Binocular superior kinetic extent	0.18(±0.05)	3.38	0.001
Avoid bumping into: Knee height objects	IVF inferior field* IVF superior field	0.11(±0.05)	2.24	0.025
Avoid bumping into: Low-lying height objects	Binocular inferior kinetic extent* Binocular superior kinetic extent	0.14(±0.06)	2.59	0.010

Table 6.8 Results of statistical comparisons between the visual field areas' AUCs. Differences between the areas, the z statistic (DeLong et al., 1988) and its significance level are given. *indicates the visual field assessment with a statistically significant greater AUC.

6.4 Discussion

In this chapter the relationship between self-reported function and visual field areas is explored using different test paradigms to determine which areas within the visual field, assessed using threshold, suprathreshold, and kinetic paradigms, are more important to reflect activities of daily living.

Both central (0-30 deg) and peripheral (past 30 deg) visual field areas, assessed using binocular threshold, binocular suprathreshold, and Esterman tests related well to self-reported function. The peripheral (past 30 deg) visual field however was a little more strongly correlated to overall and mobility self-reported function than the central (0-30 deg) for binocular threshold, and Esterman results. For these two assessments, the peripheral field was also the best predictor of both overall and mobility related self-reported function, explaining between 40% and 48% of variance in the results. The peripheral visual field assessed using the binocular threshold paradigm was selected as significantly better predicator of difficulty bumping into waist height objects, and knee height objects when compared to the central binocular threshold score in an ROC analysis. That the peripheral visual field is important for mobility function reflect findings of Experiment 1 as discussed in Chapter 3.

Unlike binocular threshold and Esterman results, the central binocular suprathreshold field score appears to be more strongly correlated with overall and mobility function than the peripheral field score, and the central binocular suprathreshold score is selected as the primary predictor of function in multiple regression analyses similarly to other studies have indicated that the central visual field is more strongly related to mobility function as discussed in Chapter 1.

The significance of the central (0-30 deg) of the visual field in particular was investigated further by comparing central binocular threshold and IVF scores. Although the central binocular threshold field score and IVF score were highly correlated, and both were significantly related with overall and mobility function, there is a slightly stronger relationship between the central field assessed binocularly than the IVF score. While both these tests assessed the central 0-30 degrees of the visual field using a threshold paradigm, the binocular threshold assessment utilized the Octopus 900's Low Vision Strategy. This paradigm uses the

4-2-1dB bracketing test method, however starts from the brightest stimulus at 0dB, thus reducing the time to reach the threshold in individuals with reduced sensitivity. The custom point pattern of the binocular threshold assessment used wider point spacing of 7.5 degrees, compared with 6 degrees used in the 24-2 assessment on the HFA. Although fewer points were tested in the central 10 degrees of the visual field, it allowed for the assessment of a greater eccentricity, and with more points between 20-30 degrees. Compared with other regions of the visual field, the central 10 degrees is not as strongly correlated with mobility function as Figure 6.2 demonstrates. A visual field assessment with test points that are a little less densely positioned to allow for a quicker assessment of the central 10 degrees but slightly more comprehensive assessment of the visual field past 20 degrees might be better at predicting perceived mobility difficulty.

As Figure 6.2 illustrates the variation in the relationship between the visual field and self-reported function is subtle across the visual field, however there are some repeatable patterns. For all (binocular static) visual field assessments, the central 0-10 degrees of the field had the weakest correlation with perceived function, and the field between 50-60 degrees eccentricity has the greatest correlation. The key function of central vision is resolution, which may not be as essential for the mobility related tasks considered here. The relationship between the visual field and function peaks twice for all three visual field tests at between 10-30 degrees, and 50-70 degrees, and there is a consistent decrease in the R^2 values for all three assessments between these two visual field eccentricities (30-50 deg). This is slightly contrary to the findings of Lovie-Kitchin et al., (1990) who assessed the binocular visual field kinetically in a small sample of subjects and scored the residual field as a solid angle in steradians. Mobility performance was assessed on an indoor course and visual field loss in the inferior mid-periphery (20 – 40 degrees) was found to adversely affect mobility more than loss of the visual field in other areas.

The results of this experiment also supports the significance of the inferior visual field for mobility function that has been demonstrated in Chapter 3, and in other studies (Lovie-Kitchin et al., 1990; Turano et al., 2004; Coleman et al., 2007; Marigold & Patla, 2008; Black et al., 2008; 2011). The inferior visual field (assessed binocularly) was consistently selected as the primary predictor of self-reported function.

6.5 Conclusion

Both the peripheral and central visual field areas have a role in reflecting the functional difficulties of people with field loss and should be considered in a functional visual field assessment regardless of the method of assessment. The significance of the inferior field to both mobility function and overall function has been demonstrated regardless of how the visual field is assessed.

Chapter 7

Experiment 2: Falls

7.1 Introduction

The analysis in Chapter 3 suggests that the clinical function variables assessed are ineffective at predicting if an individual had fallen in the previous 12 months. Other predictors of falling have been suggested in the literature which include the fear of falling (Howland et al., 1993; Arfken et al., 1994; Tinetti et al., 1994; Fessel & Nevitt, 1997; Howland et al., 1998; Lachman et al., 1998) and reduced participation in social activities (Tinetti et al., 1994; Cumming et al., 2000).

In this chapter results from two instruments, the Falls Efficacy Scale International (FES-I) (Yardley et al., 2005) and the Adelaide Activities Profile (AAP) (Clark & Bond, 1995) are analysed to determine if visual field measures as determined in Experiment 2 are a better indication of fear of falling/or and activity limitation than history of falls.

7.2 Methods

7.2.1 Falls Efficacy Questionnaire

The relationship between fall frequency and the fear of falling is well documented (Howland et al., 1993; Tinetti et al., 1994; Arfken et al., 1994; Fessel & Nevitt, 1997; Howland et al., 1998; Lachman et al., 1998). Some studies have used a single questionnaire item to determine fear of falling (Vellas et al., 1987; Afken et al., 1994; Franzoni et al., 1994; Liddle & Gilleard, 1995; Howland et al., 1998), although it is suggested self-perception of global traits like fear are poor predictors of actual behaviour (Mischel, 1968). Expanding from a rudimentary dichotomous single item measure to a continuous measure allows the discrimination between different levels of fear and enables the assessment of fear of falling in different activities (Yardly et al., 2005). Falls related self-efficacy questionnaires have shown to correlate with single item measures of fear of falling, and to predict decline in activities of daily living (Tinetti et al., 1990; Tinetti et al., 1994; Hill et al., 1996; Mendes de Leon et al., 1996; Myers et al., 1996).

The Falls Efficacy Scale (FES) (Tinetti et al., 1990; Tinetti et al., 1994) in particular has been shown to be more sensitive at assessing the fear of falling than other measures (Tinetti et al., 1990; Tinetti et al., 1994; Myers et al., 1996). However, there have been suggestions that the original FES could be improved as a measure of fear of falling. The original FES assesses self-efficacy or confidence in performing certain activities without falling; although there may not be a direct relationship between self-efficacy and the fear of falling since self-efficacy is likely greater influenced by estimations of functional capability and not with fear and anxiety (McKee et al., 2002). The 10-category measure employed for responses to the original FES has also been criticised, and narrower category discrimination may be easier for respondents (Lachman et al., 1998). Other criticisms surround the items of the original FES. The original items refer to very basic activities and omit more demanding activities which may be more relevant to higher functioning respondents (Yardley et al., 2005). The original FES also fails to address fears relating to social activities despite the fear of social consequences of falling being a principal concern for patients (Lachman et al., 1988; Yardley & Smith, 2002).

Yardley et al., (2005) set out to develop the original FES into a measure of fear of falling that assesses a wide range of both physical and social activities, and that is suitable for use in a range of language and cultural contexts. Besides asking participants to report the number of falls, as defined in the Merck Manual (Merck et al., 2011), The Prevention of Falls Network for Dissemination (PRoFouND) and WHO, in the past 12 months, this modified and validated version of the FES, (the Falls Efficacy Scale- International, or FES-I) was also used in this study. The FES-I comprises 16 items, and participants were asked to grade their level of concern about falling when carrying out each activity on a four point scale (1 – not concerned, 4 – very concerned). Items are show in Appendix 1.4.

7.2.2 Adelaide Activities Profile

Fall history and the fear of falling have been shown to be related to activity restriction (Vellas et al., 1987; Howland et al., 1998; Yardly et al., 2002; Delbaere et al., 2004), and in particular to reduced participation in social activities (Tinetti et al., 1994; Cumming et al., 2000). The relationship between activity participation and falls appears to be a bidirectional one. Lamoureux et al., (2010) assessed a range of clinical function and demographic variables of a sample of individuals with low vision and found that only non-participation in physical activity was independently and significantly associated with falls. Others have reported similar findings (Tinettii et al., 1988; Gregg et al., 2000; Gillespie et al., 2001). Therefore an additional measure of activity levels was also included as a potentially useful indicator related to falls.

The Adelaide Activities Profile (AAP) (Clark & Bond, 1995) was developed from the Frenchay Activities Index (Holbrook & Skilbeck, 1983) which assessed the activity levels of patients following a stroke. The AAP contains 21 items, and participants were asked to report frequency of activities on a four point scale that was tailored to individual items. Items are show in Appendix 1.5.

7.2 Results

Participants were initially asked to report the number of falls in the previous 12 months. While 96% of the sample reported between zero and ten falls during this period, two participants reported a higher, outlying fall frequency (Figure 7.1). To limit the effect of these outliers on results, the falls data were dichotomised into the following groups: individuals who had reported at least one fall in the previous 12 months, and those who had not fallen at all during this period. As the descriptive statistics in Table 7.1 show, 56% of participants reported falling at least once in the previous 12 months.

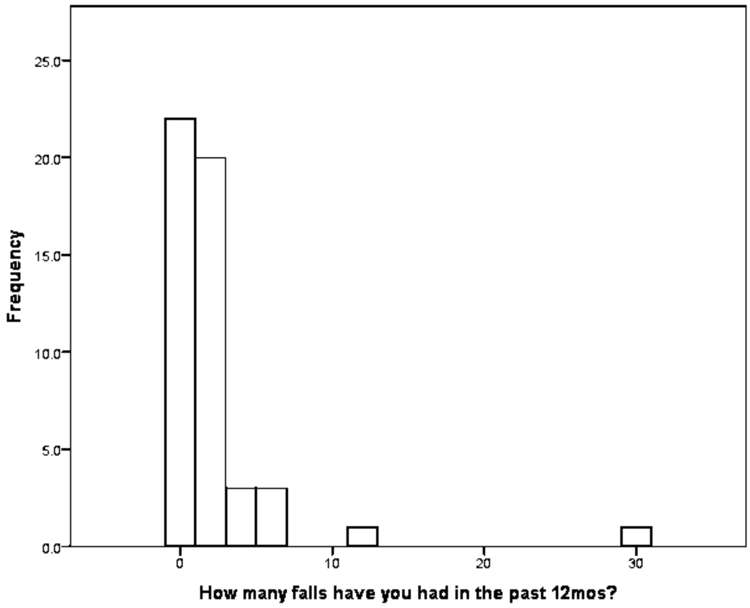


Figure 7.1 Histogram showing the distribution of the number of reported falls in the previous 12 months.

How many falls have you had in the past 12months? (n)	
Median (25% IQ-75% IQ)	1(0-2)
Min-max	0-30
Have you fallen in the previous 12mos?	
Yes	28
No	22

Table 7.1 Descriptive statistics of reported fall history.

7.2.1 Falls Efficacy Scale

Rasch analysing the ordinal data from the FES-I allowed for interval data to be derived regarding the degree of concern about falling of individual participants (person measures) and individual items (item difficulties). Higher derived person measures reflect higher ability to complete a task without the fear of falling, and higher item difficulties indicate a reduced ability required to achieve the item, i.e. an "easier" item.

	Fear of falling	**SE**	**Infit mnsq**	**Oufit mnsq**
Walking on a slippery surface	-2.38	0.21	1.09	1.03
Walking on an uneven surface	-1.82	0.20	0.56	0.54
Going up or down stairs	-1.24	0.20	1.13	1.14
Walking up or down a slope	-0.86	0.21	0.80	0.78
Going to a place with crowds	-0.82	-0.21	1.15	1.06
Walking around outside	-0.69	0.21	0.81	0.73
Going to the shop	-0.34	0.21	0.87	0.83
Visiting a friend/relative	-0.20	0.22	0.55	0.56
Going out to a social event	-0.10	0.22	0.91	0.87
Reaching up or bending down	0.20	0.23	1.26	1.37
Taking a bath or shower	0.41	0.24	1.38	1.28
Answering the telephone	1.27	0.28	1.23	0.85
Cleaning the house	1.27	1.27	0.83	1.03
Getting dressed/ undressed	1.52	0.30	1.86	2.05
Getting in or out of a chair	1.72	0.32	1.02	1.20
Preparing simple meals	2.05	0.35	1.62	0.74

Table 7.2 Item parameters of the 16 items of the FES-I as determined by Rasch analysis. Items are ordered by the degree of concern about falling, with the item most feared to result in a fall first. Infit and outfit mnsq values, indicating the fit of the item to the underlying unidimensional construct are given. All items were answered by all participants (n=50).

Person measures were derived from the data set directly, using all 16 items (Table 7.2). The person separation is 2.47 (Reliability 0.86), indicating that individuals can be reliably ordered by the instrument in terms of their level of perceived ability. Item separation is 4.48 (Reliability 0.95), indicating that items can be reliably ordered in terms of their difficulty. Targeting is however poor with a mean person measure of -1.66±1.69 logits. The low mean person measure indicates that the current sample has a higher ability to achieve items with little or no concern about falling, on average, than the questionnaire is aimed at.

The fit of the items was next considered, as an initial representation of how well the questions fitted a unidimensional construct. Items with infits and outfits within the range of 0.5 to 1.5 mean square are considered to show adequate fit (Linacre, 2014). There was one mis-fitting item with a fit in the range between 1.5 and 2.0 and a further one with a fit slightly greater than 2.0 (outfit of 2.05). These item fits were considered acceptable. Using all items in the analysis also allows comparability of the questionnaire between this study and others that used the same instrument (Yardley et al., 2005; Kempen et al., 2007; Delbaere et al., 2010).

An alternative analysis was also considered. The item with a fit greater than 2 does have the potential to distort or degrade the measurement system (www.rasch.org/rmt/rmt83b.htm). The analysis was therefore re-run with that item (getting dressed and undressed) excluded. Person separation was then 2.54, item separation 4.63, and 2 items had in or outfits between 1.5 and 2. Comparison of the original analysis of 16 items with the reduced analysis of 15 items (Linacre, 2010b) gives a strong correlation of 0.997 ($p<0.001$), although a repeated measures t-test suggests that a statistically significant difference exists between the two person measures ($t=7.84$, $p<0.001$). Whilst the item reduced scale might represent a more rigorous interpretation of unidimensional fear of falling, it removes information from the scale that is useful. The 16 item person measures were used to reflect overall fear of falling in the remainder of the results.

7.2.2 Adelaide Activities Profile (AAP)

The AAP contains 21 items, and participants were asked to report frequency of activities on a four point scale that was tailored to individual items. Descriptive statistics of the ordinal data are provided in Table 7.3.

	Frequency
How often have you prepared a main meal?	
Never	4
Less than once a week	3
1-2 times a week	11
Most days	32
How often have you washed the dishes?	
Less than once a week	3
1-2 days a week	3
Most days	6
Every day	38
How often have you washed the clothes?	
Never	5
About once a month	4
About once a fortnight	4
Once a week or more	37
How often have you done light housework?	
Never	0
Once a fortnight or less	6
About once a week	15
Several days a week	29
How often have you done heavy housework?	
Never	5
About once a month	7
About once a fortnight	10
Several days a week	28
How many hours of voluntary or paid employment have you done?	
None	15
Up to 10 hours a week	13
10-30 hours a week	12
More than 30 hours a week	10
How often have you cared for other family members?	
Never	0
About once a month	19
About once a fortnight	3
Once a week or more	28
How often have you done household shopping?	
Never	0

About once a month	1
About once a fortnight	2
Once a week or more	47
How often have you done personal shopping?	
Never	2
Once in three months	17
About once a month	18
Once a fortnight or more	13
How often have you done light gardening?	
Never	15
About once a month	8
About once a fortnight	5
Once a week or more	22
How often have you done heavy gardening?	
Never	22
About once a month	8
About once a fortnight	8
Once a week or more	12
How often have you done household and/or car maintenance?	
Never	20
Once in three months	16
About once a month	5
Once a fortnight or more	9
How often have you needed to drive a car or organise your own transport?	
Never	0
Up to once a month	3
Up to once a fortnight	1
Once a week or more	46
How often have you spent time on a hobby?	
Never	2
About once a month	5
About once a fortnight	4
More than once a week	39
How many telephone calls have you made to friends or family?	
None	0
Up to three calls a week	21
4-10 calls a week	17
Over 10 calls a week	12
How often have you invited people to your home?	
Less than once a fortnight	24
About once a fortnight	7
About once a week	8
More than once a week	11
How often have you participated in social activities at a centre such as a club, a church, or a community centre?	
Less than once a month	15

About once a month	16
About once a fortnight	5
More than once a week	14
How often have you attended religious services or meetings?	
Never	32
About once a month	9
About once a fortnight	1
Once a week or more	8
How often have you participated in an outdoor social activity?	
Never	20
About once a month	12
About once a fortnight	7
Once a week or more	11
How often have you spent some time outdoors participating in a recreational or sporting activity?	
Never	20
About once a month	3
About once a fortnight	8
More than once a week	19
How often have you walked outdoors for 15 minutes of more?	
Once a month or less	3
About once a fortnight	4
About once a week	8
Most days	35

Table 7.3 Descriptive statistics of the AAP scores.

Response options to the 21 items of the AAP were tailored to individual items, so each number on the four point scale indicates a different frequency of undertaking the activity. An initial analysis that involved converting the responses to a single Andrich rating scale (0, 1, 2, 3) where 0 is the least frequency of activity and 3 the greatest, revealed the two central options (1, 2) were used infrequently relative to others (0, 3). These two categories were collapsed into one to form a three category scale (0, 1, 2). Interval data were then derived from the modified ordinal scale in a Rasch analysis. A low person measure indicated a lower level of activity and a high score greater level of activity.

Person measures were derived from the data set directly, using all 21 items. The person separation is 1.38 (Reliability 0.66), indicating that instrument is not able to reliably order individuals in terms of their level of activity. Item separation is 3.80 (Reliability 0.94), indicating that items can be reliably ordered in terms of their frequency. Targeting, with a mean person measure of 0.71±0.64 logits, indicates that the current sample is as active, on average, as the questionnaire is aimed at. The variance explained by the measures is low (37.2%). In terms of item fit, there was one mis-fitting item with a fit in the range between 1.5 and 2.0. Fits were therefore considered acceptable and all items are considered to contribute to the analysis.

7.2.3 Bivariate correlations

The relationship between fall data and other variables was investigated. Due to the multiple number of comparisons performed (25) a more stringent significance level is more appropriate for these tests. A Bonferroni corrected significance level of $p=0.002$ was used.

None of the demographic and clinical variables were found to significantly associate with fall history in the previous 12 months, including fear of falling (Table 7.4). Fear of falling was significantly related to the binocular threshold peripheral (30-60 deg) visual field ($R^2=0.19$, $p<0.001$) and the inferior field ($R^2=0.20$, $p<0.001$). Participants with worse visual field scores in these areas reported a greater fear of falling. The binocular threshold central and superior field areas were not significantly related to fear of falling. The overall (0-60 deg) binocular threshold field score also did not relate significantly to fear of falling, although the binocular kinetic (R^2=0.27, p<0.001), and Esterman (R^2=0.23, p<0.001) scores did (Figure 7.2). Fear of falling was also significantly related to overall self-reported function (R^2=0.23, p<0.001) but not to self-reported mobility function (R^2=0.12, p=0.013). None of the variables were found to significantly associate with activity levels.

	Have you fallen in the previous 12mos?	Falls Efficacy Scale	Adelaide Activities Profile
Gender	U=302.00	U=261.00	U=290.00
Use of mobility aids	U=293.00	U=217.00	U=292.00
Use of low vision aids	U=305.00	U=135.00	U=250.00
Have you fallen in the previous 12mos?		U=217.50	U=237.50
Age	U=286.00	R^2=0.00	R^2=0.05
Duration of visual impairment	U=305.50	R^2=0.17	R^2=0.05
Number of prescribed medication	U=232.50	R^2=0.01	R^2=0.02
Number of comorbidities	U=278.50	R^2=0.04	R^2=0.02
Registration status	U=302.00	R^2=0.05	R^2=0.02
Falls Efficacy Scale	U=217.50		R^2=0.01
Adelaide Activities Profile	U=237.50	R^2=0.01	
Overall self-reported function	U=293.00	R^2=0.23*	R^2=0.00
Mobility self-reported function	U=281.50	R^2=0.12	R^2=0.00
Binocular VA	U=288.00	R^2=0.10	R^2=0.01
Binocular CS	U=302.50	R^2=0.10	R^2=0.03
Binocular near reading acuity	U=275.50	R^2=0.13	R^2=0.01
Overall (0-60 deg) threshold visual field score	U=236.00	R^2=0.17	R^2=0.00
Central (0-30 deg) threshold field score	U=242.00	R^2=0.15	R^2=0.00
Peripheral (30-60 deg) threshold field score	U=223.00	R^2=0.19*	R^2=0.00
Superior (0-60 deg) threshold field score	U=259.00	R^2=0.12	R^2=0.00
Inferior (0-60 deg) threshold field score	U=228.00	R^2=0.20*	R^2=0.00
Binocular suprathreshold score	U=235.00	R^2=0.14	R^2=0.01
Binocular kinetic solid angle	U=236.00	R^2=0.27*	R^2=0.00
Esterman score	U=209.00	R^2=0.23*	R^2=0.01
IVF score	U=235.00	R^2=0.14	R^2=0.00

Table 7.4. Relationship between the variables assessed, and fall history and fear of falling. Mann-Whitney U tests were conducted for the dichotomous predictors, and the continuous and ordinal variables were compared to self-reported function in 2-tailed Spearman's rho bivariate correlations (*p<0.002, for all others p≥0.002).

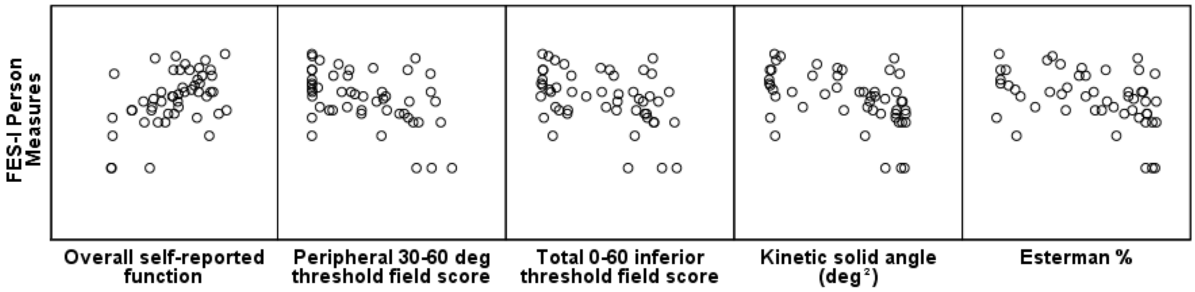


Figure 7.2 Graphical representation of the significant (p<0.002) relationships between FES-I person measures and overall self-reported function, and visual field scores.

7.2.4 ROC analysis

Ordinal responses to items on the FES-I were dichotomised to allow for an ROC analysis. Respondents were separated into the following two groups: those who reported fear of falling when undertaking a task, and those who reported no fear. Participants who reported at least slight fear of falling with the task, or a fear of 2 or greater were all assigned to the first group. Each question was considered separately, with the participants' dichotomised responses acting as a classification of whether fear of falling with each task was reported.

The AUCs suggest that for the majority of tasks, the visual field assessments were poor predictors of fear of falling. For some tasks however, the AUCs were greater, and significantly different from 0.5, indicating that for these tasks a visual field measure was effective at predicting fear of falling. These tasks include "going to the shop", "reaching up or bending down" and "walking up or down a slope". While binocular threshold, binocular suprathreshold, and IVF scores produce AUCs significantly different from 0.5 for three or four tasks, AUCs for Esterman and binocular kinetic scores were significantly greater than 0.5 for six and seven tasks respectively. Furthermore, when comparisons where made between the

AUCs to determine if a visual field assessment was better as predicting fear of falling with certain tasks, the Esterman and the binocular kinetic tests were both significantly more effective than three other visual field assessments at determining whether a participant reported fear of falling “reaching up or bending down” and “answering the telephone (before it stops ringing)” (Table 7.6).

	Binocular threshold (dB)	Binocular suprathreshold (%)	Binocular kinetic solid angle (deg^2	Esterman (%)	Integrated visual field (dB)
Cleaning the house	0.52(±0.10)	0.50(±0.10)	0.56(±0.09)	0.54(±0.10)	0.50(±0.09)
Getting dressed/ undressed	0.52(±0.11)	0.49(±0.11)	0.55(±0.10)	0.52(±0.10)	0.51(±0.10)
Preparing simple meals	0.47(±0.12)	0.45(±0.13)	0.59(±0.10)	0.56(±0.10)	0.42(±0.12)
Taking a bath or shower	0.56(±0.08)	0.56(±0.08)	0.57(±0.08)	0.59(±0.08)	0.56(±0.08)
Going to the shop	0.71(±0.08)*	0.68(±0.08)*	0.72(±0.08)*	0.71(±0.08)*	0.70(±0.08)*
Getting in or out of a chair	0.61(±0.09)	0.59(±0.10)	0.63(±0.08)	0.51(±0.09)	0.62(±0.09)
Going up or down stairs	0.55(±0.11)	0.52(±0.11)	0.60(±0.11)	0.56(±0.11)	0.53(±0.11)
Walking around outside	0.66(±0.08)	0.65(±0.08)	0.71(±0.08)*	0.67(±0.08)*	0.63(±0.09)
Reaching up or bending down	0.67(±0.08)*	0.68(±0.08)*	0.69(±0.08)*	0.75(±0.08)*	0.64(±0.08)
Answering the telephone	0.63(±0.10)	0.63(±0.10)	0.73(±0.08)*	0.69(±0.09)*	0.62(±0.10)
Walking on a slippery surface	0.81(±0.11)*	0.76(±0.10)	0.75(±0.10)	0.80(±0.10)*	0.86(±0.09)*
Visiting a friend/relative	0.65(±0.08)	0.63(±0.08)	0.67(±0.08)*	0.65(±0.08)	0.62(±0.08)
Going to a place with crowds	0.61(±0.08)	0.57(±0.08)	0.61(±0.08)	0.63(±0.09)	0.60(±0.08)
Walking on an uneven surface	0.62(±0.11)	0.59(±0.11)	0.59(±0.10)	0.61(±0.12)	0.59(±0.11)
Walking up or down a slope	0.77(±0.07)*	0.75(±0.08)*	0.82(±0.07)*	0.78(±0.08)*	0.78(±0.07)*
Going out to a social event	0.66(±0.08)	0.64(±0.08)	0.67(±0.08)*	0.66(±0.08)	0.65(±0.08)

Table 7.5 Receiver operating characteristics (ROC) areas under the curves (AUC) describing the relative performance of visual field assessments in predicting fear of falling when undertaking activities of daily living. *indicates AUCs that are significantly ($p \leq 0.05$) different from 0.50.

Mobility task	Visual field tests being compared	Difference between areas (±std)	z statistic	Significance value
Reaching up or bending down	Esterman* Binocular threshold	0.08(±0.03)	2.70	0.007
Reaching up or bending down	Esterman* Binocular suprathreshold	0.07(±0.03)	2.48	0.013
Reaching up or bending down	Esterman* IVF	0.11(±0.04)	2.94	0.003
Answering the telephone	Binocular kinetic* Binocular threshold	0.09(±0.04)	2.46	0.014
Answering the telephone	Binocular kinetic* Binocular suprathreshold	0.10(±0.03)	2.90	0.004
Answering the telephone	Binocular kinetic* IVF	0.11(±0.05)	2.30	0.022

Table 7.6 Results of statistical comparisons between the visual field assessments' AUCs. Differences between the areas, the z statistic (DeLong et al., 1988) and its significance level are given. *indicates the visual field assessment with a statistically significant greater AUC.

7.3 Discussion

Fear of falling related significantly to some visual field measures, with a weak relationship weak binocular kinetic (R^2=0.27, $p<0.001$) and Esterman (R^2=0.23, $p<0.001$) scores, where participants with greater field loss reported greater fear of falling. These findings are consistent with others (Ramulu et al., 2012; Yuki et al., 2013) who have found greater fear of falling in glaucoma patients with greater field loss. However, Friedman et al., (2002) did not find that the visual field was a significant predictor of fear of falling assessed as a dichotomous response to a single question, and Turano et al., (1999) also did not report any significant association between fear of falling and glaucomatous field loss.

It is likely that a stronger relationship between the fear of falling and visual fields was not found, since like falling, the fear of falling has multifactorial and interacting predisposing causes, and a larger sample size would therefore have been needed to tease out any weak existing relationship in the present study.

Some studies have suggested greater correlations between specific field areas and fall history. Freeman et al., (2007) also suggest that losses in the peripheral visual field (20-60 deg) are a more important risk factor for falling than the central visual field (0-20 deg). The binocular threshold peripheral field score in the current study was significantly related to fear of falling (R^2=0.19, p=0.002), while the correlation of the central field area with fear of falling was not significant at the Bonferroni significance level p=0.002 (R^2=0.15, p=0.005). While the binocular threshold superior score was not significantly related to fear of falling in the current study (R^2=0.12, p=0.014), a significant relationship was found between fear of falling and the inferior field score (R^2=0.20, p<0.001). Black et al., (2011) also found the inferior field was significant in predicting risk of falls amongst patients with glaucoma.

Fear of falling was also significantly associated with overall self-reported function (R^2=0.23, p<0.001), reflecting other studies that also demonstrate a correlation between fear of falling and function (Tinetti et al., 1990; Tinetti et al., 1994; Hill et al., 1996; Mendes de Leon et al., 1996; Myers et al., 1996; Yardley et al., 2000).

No significant correlations were found between measures of clinical function and falls history, despite correlations being documented in the literature (Glynn et al., 1991; Friedman et al., 2002). Visual field loss has been shown to increase the risk of falling in other studies as discussed in Chapter 1 (Jack et al., 1995; Klein et al., 1998; Ivers et al., 1999; Ramrattan et al., 2001; Klein et al., 2003; Freeman et al., 2007; Haymes et al., 2007; Patino et al., 2010).

Level of activity has previously been seen to be related to fall history (Vellas et al., 1987; Campbell et al., 1989; King & Tinetti, 1995; Friedman et al., 2002; Lamoureux et al., 2010 Schepens et al., 2012) and fear of falling (Howland et al., 1998; Tinetti et al., 1988; Howland et al., 1993; Tinetti et al., 1994; King & Tinetti, 1995; Cumming et al., 2000; Friedman et al., 2002; Yardley et al., 2002; Delbaere et al., 2004), but in the present study the relationship between the Adelaide Activities Profile and fall history or fear of falling was not significant. Unlike Clark & Bone (1995), the present study did not find that lower levels of activity were associated with greater difficulty with activities of daily living. No significant associations were also found between the Adelaide Activities Profile and any of the clinical measures, including visual field scores. This is contrary to Black & Wood (2013) who suggest that greater glaucomatous visual field loss is associated with activity restriction. The Adelaide Activities Profile has limitations which could explain why no significant relationships were found including problems with its inconsistent four-point scale and low person separation. Furthermore, Bond et al., (1995) suggests that the 11/21 questionnaire items reflecting domestic tasks had the potential to discriminate by gender, the presence or absence of a partner, and whether or not the subject lived alone.

Studies have demonstrated an association between an increased risk of falling and musculo skeletal disorders (Campbell et al., 1989; Friedman et al., 2002), the total number of medications taken (Campbell et al., 1989; Chang & Do, 2015), the use of mobility aids (Arfken et al., 1994), female gender (Kressig et al., 2001; Stevens et al., 2006), and old age (Chang & Do, 2015). No significant correlations were found between fall history and any demographic factors in this study.

7.4 Conclusion

Fall history and activity level are not significantly associated with any demographic or clinical factors, levels of activity, or perceived function. The visual field assessed using a custom binocular kinetic test, or Esterman assessment may relate to fear of falling however. The inferior and peripheral regions of the visual field in particular may be a better predictor of fear of falling. Falls have multifactorial and interacting predisposing causes, and retrospective recall of falls is unreliable (Cummings et al., 1988). The fear of falling is easier for patients, especially elderly patients, to report/recall (Yardley et al., 2002), and may be more useful for relating to clinical measures of function.

Chapter 8

Other clinical factors

In this chapter, additional analyses from Experiment 2 are reported, covering the acceptability of the visual field paradigms to patients, and the relationship between visual field loss and visual impairment registration status.

8.1 Patient acceptability

8.1.1 Introduction

Many patients dislike performing visual field tests (Gardiner & Demirel, 2008; Glen et al., 2014), and feel visual field tests are time consuming, old fashioned and tiring (Glen et al., 2014). Discussions in previous chapters rely on statistical analysis to help determine the most effective visual field strategy for functional field assessment. In this chapter qualitative methods are used to investigate patients' perspectives on the visual field assessment. Further objective parameters including test durations are also considered to help devise optimal strategies for functional field assessment.

8.1.2 Methods

The visual field data reported in this chapter is that of Experiment 2 and is described in previous chapters. The average duration of each field assessment was noted.

Participants were asked if they recalled having had a visual field assessment previously, and if they had ever seen their visual field results. Patient acceptability of visual field assessments was determined using a 5 item binary response questionnaire (Figure 8.1), administered after completion of each field test. Three items in the questionnaire were taken from a study of patient acceptability of optic disc imaging (Tay et al., 2004) to determine if participants felt the tests were comfortable, and test durations were acceptable. Participants were also asked if they experienced difficulty mainting concentration during the assessment. A further question determined if participants would be happy to conduct the assessment on future clinic visits. After explaining results of the tests participants were asked if test outputs were easily understood. After completion of all field tests, participants were also requested to rank the tests based on their acceptability, and usefulness to them of the results presented. Since questionnaire responses can be restricted by wording of the items and provide little opportunity for clarification or elaboration (Glen et al., 2014), participants were allowed to make further comments relating to acceptability and output of the tests. Field notes were taken during these discussions, and comments were categorised according to common themes.

Would you mind having this test done again in practice?

Yes	No
○	○

Was this test comfortable?

Yes	No
○	○

Was this test too long?

Yes	No
○	○

Did you have a problem maintaining concentration/fixation during the test?

Yes	No
○	○

Is the output of the test easy to understand?

Yes	No
○	○

Figure 8.1 Five item questionnaire used to determine patient acceptability

8.1.3 Results

All participants used in the study reported previous visual field testing, although 28% had not seen their visual field results before.

	Participants happy to repeat test in clinic	Participants who found test comfortable	Participants who found the test of acceptable length	Participants who did not lose concentration during test	Participants who felt test output was easy to understand
Binocular threshold	87%	84%	72%	45%	100%
Binocular suprathreshold	90%	93%	90%	57%	100%
Binocular kinetic	98%	98%	95%	81%	98%
Esterman	82%	88%	59%	47%	97%
IVF	71%	65%	52%	33%	100%

Table 8.1 Participant responses to the 5-item acceptability questionnaire (n=50).

Results of the 5 item questionnaire are provided in Table 8.1. After explanation of field results, almost all participants found outputs of all tests easy to understand. Although the monocular fields were later combined to create IVF data, the outputs shown to participants were the two monocular grey scale plots. The smallest proportion of participants found the IVF assessment (separate monocular threshold tests) comfortable (65%), whereas all other tests were reported comfortable by at least 84% of participants. Participants reported the greatest difficulty maintaining concentration during the IVF assessment, unlike the kinetic test where 81% reported no trouble maintaining concentration. At least 71% of participants were happy to repeat these tests in clinic.

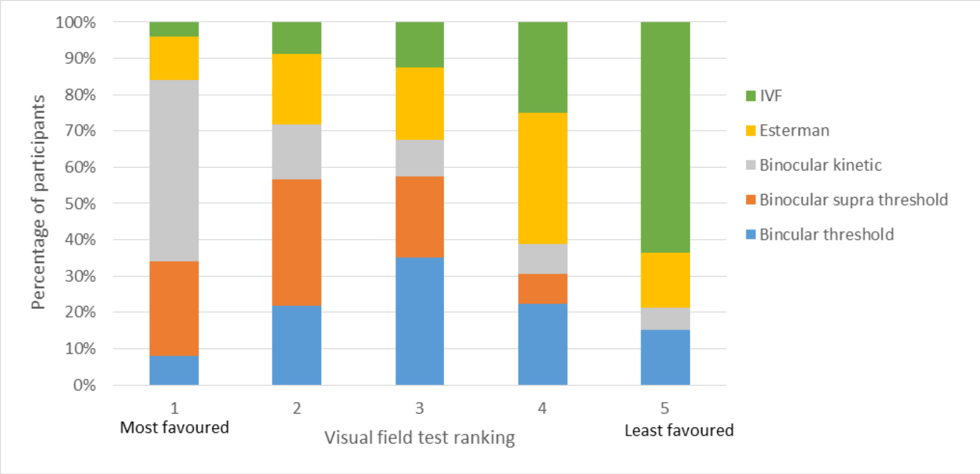


Figure 8.2 Ranking of visual field tests based on patient acceptability.

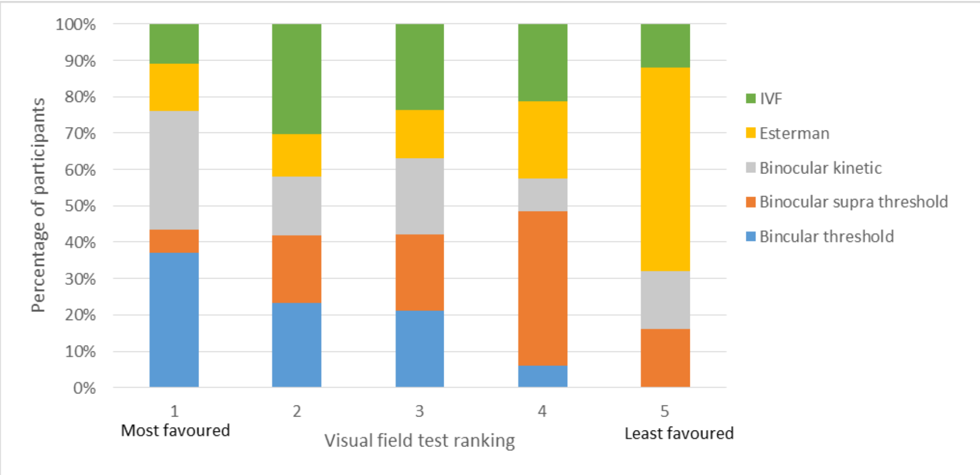


Figure 8.3 Ranking of visual field tests based on usefulness of output.

The most favoured assessment was the kinetic assessment (Figure 8.2), while the IVF was ranked the least favourite test by over 60% of participants. Binocular threshold and binocular kinetic test outputs were each ranked most favourable by 30-40% of participants. The Esterman produced the least favourable output (Figure 8.3).

	No of participants
Binocular tests more comfortable than monocular tests	11
Kinetic assessment is pleasant	7
Long periods of time when no lights are seen is disheartening	6
Concern about reliability of shorter tests	6
More confident that uniformly bright lights in the binocular suprathreshold assessment are seen	5
Bright lights at the start of the binocular threshold assessment are encouraging	4
More hesitant about dim lights in binocular threshold assessment	3
Shorter tests are preferred	3

Table 8.2 Key themes relating to the general acceptability of the visual field tests from comments made by participants

Table 8.2 indicates the common themes from comments made by participants about the general acceptability of the visual field tests. Shorter tests were preferred, and the kinetic assessment in particular was favoured. Participants found the kinetic assessment pleasant, less stressful, and encouraging. Comments were made indicating reassurance in knowing that a light will be seen eventually. A couple of participants suggested that the kinetic assessment was more fun and engaging than the other static tests, and one remarked on the assessment's novelty value. However a number of participants also expressed concern that the test was too basic or too short, and that the accuracy of results would be compromised by the test's rapidity. One participant suggested that the short test duration of the kinetic assessment did not give them much time to get used to the paradigm, and another suggested conducting a trial run before performing the assessment. Participants were happy to conduct a longer test if they knew that results would be more beneficial to the practitioner. These discussions suggest that patients' impressions of tests were irrelevant compared with their impression of usefulness of test results to clinicians. A number of comments were made indicating preference for binocular tests, which were reported as more comfortable, and less tiring than monocular assessments. Participants also expressed preference for the Octopus 900 perimeter over the HFA, with a couple noting reduced comfort with the latter. Some participants preferred the uniformly bright lights on the binocular suprathreshold assessment; however others found the bright lights at the start of the binocular threshold assessment encouraging. Numerous comments were made expressing a dislike for periods during field assessment when no lights are seen. Many participants reported losing focus and concentration during these periods. One participant reported feeling greatly disheartened and anxious during these periods.

	No of participants
Outputs of tests that show the peripheral field are useful	4
Perceived greater detail with monocular threshold results	4
Points on suprathreshold output plots are difficult to see	3
Results that show greater residual field favoured	2
Binocular plots of visual field preferred over monocular results	2

Table 8.3 Key themes relating to the output of visual field tests from comments made by participants.

Table 8.3 summarises key themes relating to the output of field tests from comments made by participants. Participants commented about the size of points on suprathreshold outputs, the Esterman output in particular, and expressed difficult viewing the results. The kinetic plot was favoured by a significant proportion of participants, with some expressing preference for plots that indicated greater levels of residual field. The kinetic plots also emphasised field that was present rather than visual field that was lost. A similar proportion of participants preferred the grey scale plots, and individuals remarked on the greater level of detail provided on a grey scale plot compared to others. In particular there was the perception of a greater degree of detail provided in the monocular threshold results. One participant did however suggest the binocular grey scale plot was "dramatic", and another indicated that they felt the plot was open to interpretation, unlike the absolute nature of suprathreshold results. A couple of participants commented on the usefulness of having their peripheral field represented, with one participant suggesting that the monocular threshold plots were an inaccurate depiction that overestimated the extent of their visual field.

Shorter tests
Brighter targets
Avoid long periods of time during test where no lights seen
No spectacles
No eye patches
Explanation of results
Octopus 900 preferred over HFA

Table 8.4 Recommendations for improving patient experience of visual field assessment, based on common themes from participants' comments.

Suggestions for improving patient experience of visual field assessment were drawn from participant comments, and the key recommendations are provided in Table 8.4. Shorter tests, with brighter targets were favoured by participants in this study. Participants preferred to conduct the assessment binocularly, with no spectacle correction or eye patches. The importance of having test results shown and explained to patients was unanimous.

The average length of time taken to undertake each visual field assessment is provided in Table 8.5 and Figures 8.3 and 8.4. The quickest test was the kinetic which took 1min 26sec (±9sec), while the mean duration of the longest test, the monocular threshold assessments was 9min 23sec (±24 sec). The kinetic and suprathreshold assessments were consistently the quickest tests to perform, while the other assessments' test duration show variance with different participants. One participant with advanced glaucomatous field loss affecting both hemifields of both eyes (Figure 8.6a) completed the binocular threshold assessment in 8 min 12 sec, while the monocular threshold assessments took in total 12 min 48 sec. Another participant with slight inferior peripheral field loss in one eye as a result of a branch retinal artery occlusion (BRAO) (Figure 8.6b) completed the monocular threshold assessments in a quicker time than the binocular threshold assessment (5 min 37 sec, and 7 min 56 sec respectively).

	Mean (±std)	**Median (25% IQ-75% IQ))**	**Range**
Binocular threshold	460.22(±18.12)	459(360-538)	248-807
Binocular suprathreshold	189.80(±6.33)	175(158-204)	150-344
Binocular kinetic solid angle	86.10(±6.34)	72.5(45-135)	36-172
Esterman	379.68(±14.64)	354(292-468)	240-574
Integrated monocular threshold	565.62(±16.08)	586.5(480-655)	337-787

Table 8.5 Descriptive statistics of test durations of visual field assessments (seconds).

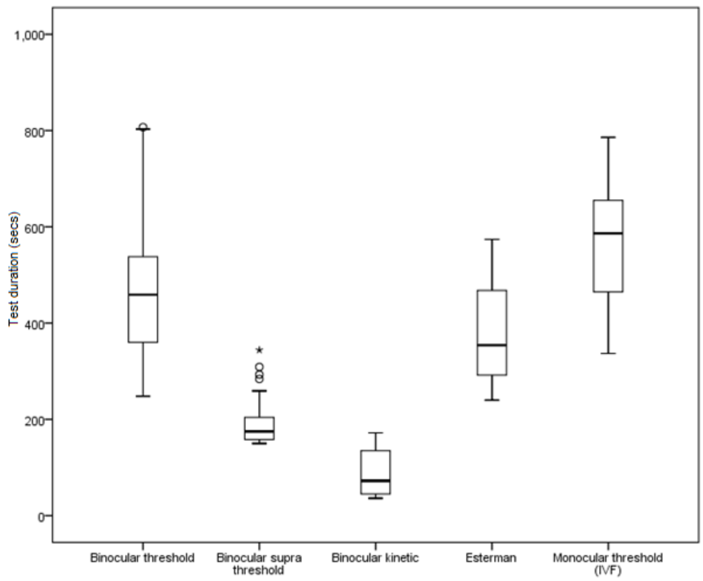


Figure 8.4 Test durations of each of the five visual field assessments.

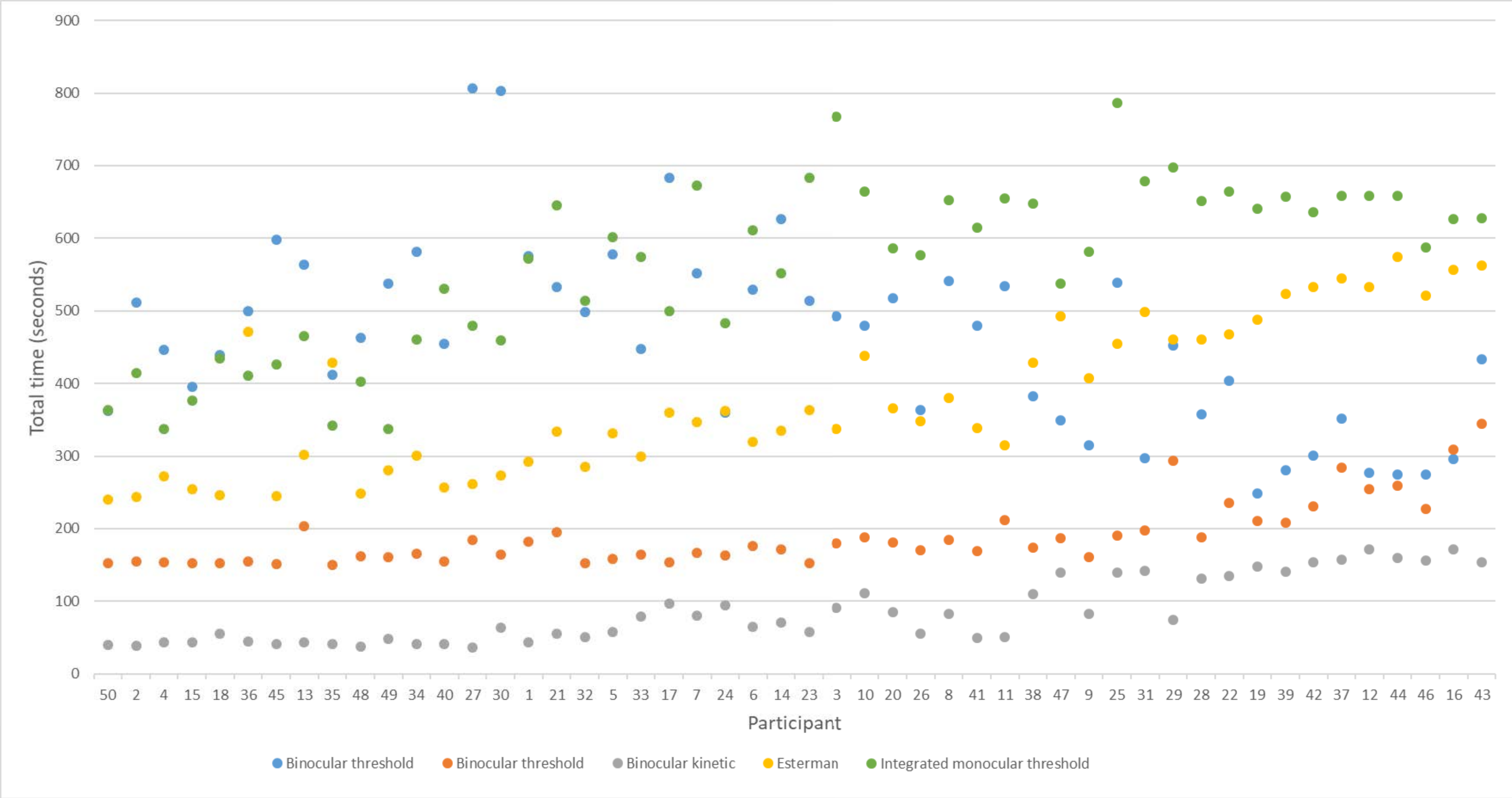


Figure 8.5 Graphical representation of test durations for visual field assessments. Participants are ordered by IVF total test duration.

a b

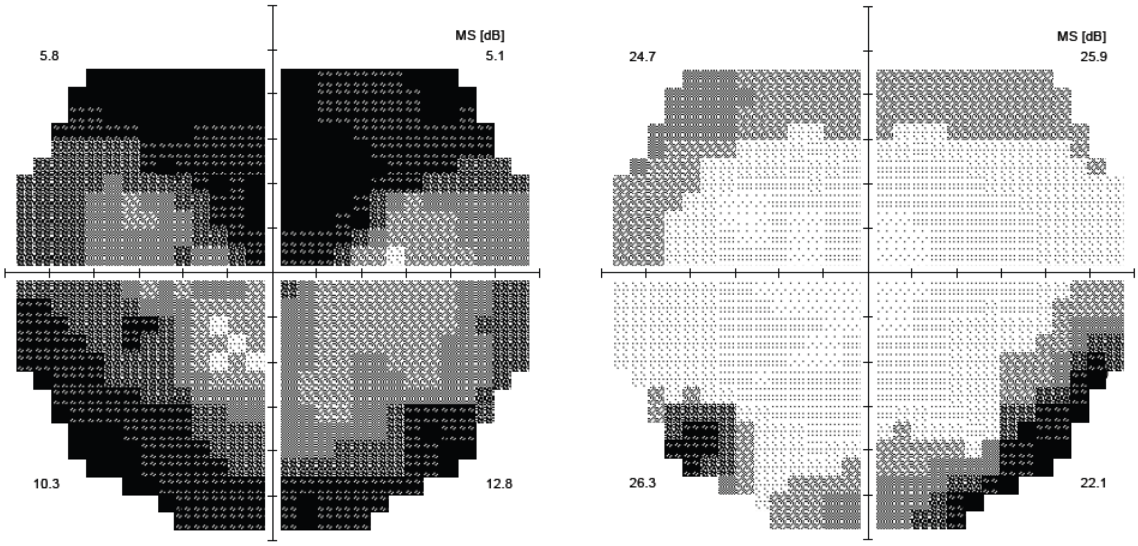


Figure 8.6 Greyscale plots from binocular threshold assessment of (a) participant with advanced bilateral glaucoma, and (b) unilateral BRAO.

8.1.4 Discussion

It is important that the patient experience when undergoing clinical tests is considered, although patients' opinion of vision testing is largely unreported. It has been suggested that this is due to difficulty objectively quantifying subjective or "human factors" of field assessment (Gardiner & Demirel, 2008; Artes et al., 2016). However, acknowledging patients' experiences may help devise effective strategies for functional vision assessment. In this chapter the visual field testing experience of individuals with visual impairment has been considered.

Although all participants had experience of visual field assessments, over a quarter of them do not recall being shown their visual field results before. This is surprising since individuals who choose to volunteer in these studies may be more motivated to participate due to having more severe disease, or holding strong opinions about their care. Glen et al., (2014) found that most patients had to specifically enquire about their visual field results, and explanation of field plots was not routinely carried out in hospital clinics. They also report that some patients felt intimidated to ask the clinician for feedback, but also that patients may be more inclined to have visual field tests more frequently should they be informed about their results. All patients in this study found value in having their visual field results explained to them.

Responses to the 5 item questionnaire were overwhelmingly positive with at least two thirds reporting even their least favoured test as comfortable. Many participants had taken part in other clinical studies previously, and may be better motivated and so respond more positively to field tests than the average patient in a clinical setting. Over two thirds of participants were happy conducting their least favoured test again in clinic. This could also be due to patients viewing the visual field assessment as a ‘necessary evil’ (Glen et al., 2014). Glen et al., (2014) reported that there was reluctant agreement for more frequent visual field testing among glaucoma patients, suggesting that although disliked, patients appreciated the benefits of the test.

Although the importance of allowing patients to view and discuss visual field results with a clinician has been documented (Glen et al., 2014), it is not known what output format is preferred by patients. The majority of participants in the current study who have previously been shown their field results are likely to have viewed greyscale plots at glaucoma clinics, although a number had only seen their Esterman results after DVLA testing at high street optometrists. The familiar grey scale plot of the binocular threshold assessment was ranked most favoured by over a third of participants. Equally favoured was the binocular kinetic output. The kinetic isopter was simple to explain and interpret, and in a number of participants, presented their residual field favourably compared to other outputs, oftentimes overestimating the degree of residual field by ignoring the presence of internal scotomas. Participants may feel that this overestimated plot reflects more closely their perceived residual field compared with other more dramatic outputs. It is known that kinetic targets are easier to detect than static targets due to the Riddoch phenomenon (Hudson et al., 1994; Zeki & FFytche, 1998), and studies have shown the difference in threshold sensitivities when examining the visual field using static and kinetic perimetry (Hudson and Wild, 1992; Schiller et al., 2006). One study suggests that this static-kinetic dissociation results in an overestimation of the static profile when assessed using a kinetic paradigm by an average of 4dB (Hudson and Wild, 1992). Approximately 80% of participants ranked the Esterman or binocular suprathreshold outputs as least favourable. Participants commented on the small size of test points on the print out of suprathreshold assessments which made the results difficult to view.

Approximately half of participants ranked the kinetic assessment the most favourably. Besides the moving stimuli being easier to detect, another reason why the kinetic assessment was preferred could be due to the novel nature of the test compared with the monocular threshold assessment routinely used in clinics. Henson & Emuh (2010) suggest that the introduction of some form of novelty to the routine and unexciting perimetric task could improve vigilance and performance. Li & Mills (1992) moved the position of the fixation target during visual field assessment and found that it improved sensitivity of the results due to increased patient alertness. Miranda & Henson (2008) asked patients to verbally report where they saw stimuli and found improvements in both sensitivity and variability. Similarly, one of the patient recommendations reported by Glen et al., (2014) in their qualitative study was to modernise the visual field test, with patients in their sample remarking that conventionally used visual field tests were old-fashioned (one participant described the visual fields test as antiquated). A novel and more engaging test strategy like the kinetic paradigm could improve vigilance and patient motivation.

A common sentiment revealed in discussions with participants was their concern about the reliability and usefulness of test results. Although shorter tests were reported most pleasant and acceptable, the clinician's judgment of test usefulness was deemed more important than patient comfort. Participants were happy to conduct a longer test if they knew that results would be more beneficial to the practitioner, reflecting evidence that suggests patients trust the practitioner to make the best decision about their care (Glen et al., 2014).

Henson & Artes (2002) report that despite reductions in test times with new threshold strategies (Bengtsson et al., 1997; Bengtsoon & Heijl, 1998), the threshold field test is still a very demanding procedure for patients. This is consistent with results of the current study. The binocular threshold and monocular threshold assessments were ranked least favourable by approximately 80% of participants. Approximately one third of the sample reported the binocular suprathreshold assessment as the most favoured test. Is it reported that there is less uncertainty about whether a stimulus was seen or not in a suprathreshold assessment, making it an easier test to perform (Henson & Artes, 2002). There were other participants however who expressed preference for the binocular threshold assessment over the binocular suprathreshold assessment in discussions. This could be due to the test strategy utilised in the binocular threshold assessment. In the Octopus 'low vision' strategy used, stimuli are presented using a 4-2-1 dB bracketing test method starting at 0dB (4000asb) in order to arrive quickly at the expected threshold level in subjects with impaired visual fields. A longer 200ms stimulus duration, rather than the standard 100ms, is also applied. This may explain why some participants, likely those with greater visual field loss, may have preferred the binocular threshold assessment.

Participants report feeling disheartened and discouraged when periods of time lapsed with no lights seen. Patients have been found to place pressure on themselves to perform well in visual field assessments (Glen et al., 2014), and clinicians are advised to encourage and reassure patients before and after testing, and be available to alleviate any concerns patients might have during testing (Glen et al., 2014). DeJong et al., (1985) suggest that the active presence of an examiner provides psychological support to help to engage the attention of patients during the test. The presence of the practitioner may restore vigilance during assessment (Henson & Emuh, 2010) and improve test result reliability (DeJong et al., 1985).

It is reported that patients find visual field testing exhausting (Gardiner & Demirel, 2008) and commonly report difficulty maintaining vigilance and attention (Henson & Emuh, 2010). Fatigue has been shown to affect perimetric performance as test duration increases (Hudson et al., 1994). This could explain why the kinetic and binocular suprathreshold assessments, the quickest of all five tests, were most favoured in the current study. Henson & Emuh (2010) measured pupil fatigue waves, the pupil oscillations that occur during periods of fatigue, during visual field assessment. They report large pupillary fatigue waves in an individual undertaking a perimetric assessment after 3-4 minutes, suggesting that the ideal test should not exceed this duration. A quicker visual field assessment is more likely to produce more reliable threshold results (Heijl & Drance, 1983; Katz and Sommer, 1986; Hudson et al., 1994), and therefore a shorter and more accurate assessment of the binocular visual field is more effective at predicting perceived mobility function than a longer monocular assessment.

While the binocular kinetic and suprathreshold assessments were consistently the shortest tests, test durations of other assessments were dependent on the extent of participants' field loss. Those with advanced loss performed the binocular threshold assessment in a shorter time than the monocular threshold assessments, likely due to the low vision test strategy utilized in the binocular threshold test. Participants with earlier field loss completed the monocular threshold assessments quicker than the binocular threshold test.

Artes et al., (2016) showed that perceptual difficulty of visual field tests is not reflected by response times, and suggests that better objective measures for “human factors” aspects in perimetry are needed to quantify test difficulty or patient acceptability. In the current study we have shown that test duration and extent of field loss are associated with patients’ experiences of visual field assessments.

8.1.5 Conclusion

Patient input is important to help devise optimal strategies for functional field assessment. Patients appreciate the importance of visual field testing despite reporting discomfort with some assessments. Previous chapters have shown that all binocular assessments of the visual field out to 60 degrees are similarly effective at predicting perceived disability in patients with peripheral field loss. Considering the paradigms used here, the Esterman assessment appears to take longer in participants with greater visual field loss, was ranked poorly for patient acceptability, and produced the least favourable test output, suggesting its unsuitability for functional field determination in individuals with low vision. The binocular threshold assessment, although producing outputs that were familiar, reflect the visual field binocularly, and illustrate the peripheral field, took a long time to perform. Similarly, the IVF is long and demanding for participants, many of whom found the monocular assessment more difficult than binocular testing, and it also reflected function slightly less well (Chapter 5) and only considers the central field. Shorter novel visual field tests like the binocular suprathreshold, and in particular the kinetic assessment used in this study are favoured by participants.

8.2 Visual field assessment and sight loss registration

8.2.1 Introduction

While sight loss registration initiates access to a range of support services that facilitate independent living and continued employment (Department of Health, 2013), a large proportion of patients eligible for registration remain unregistered, in particular patients exhibiting visual field loss alone and those with permanent visual loss receiving treatment (Robinson et al., 1994; Bunce et al., 1998; King et al., 2000; Barry & Murray, 2005). There is very poor consistency among ophthalmologists in visual impairment registration of glaucoma patients with significant field loss, and current visual field criteria is open to significant subjective interpretation, with imprecisely defined categories such as “very restricted” and “gross defect” (Chapter 1) (Guerin et al., 2014). In this chapter the relationship between sight loss registration and perceived and measured clinical function is considered.

8.2.2 Methods

The visual field data reported in this chapter is that of Experiment 2 and is described in previous chapters.

Participants were asked to report their current sight loss registration status. Reasons for non-registration were also recorded. Participants were asked if they were aware of their visual field loss binocularly, and to describe the nature of noticeable visual field loss.

Participants were categorised based on their visual acuity and visual field scores. Visual acuity groups were defined as follows: participants with binocular VA worse than 6/60, and better than 6/60. Two broad categories of visual field loss based on criteria applied by King et al., (2000), and that were considered to indicate visual field loss severe enough to warrant registration were used: participants with an average visual field extent of greater than 15 degrees radius, and those with an average visual field constriction to within at least 15 degrees radius. The sample was also divided based on treatability of primary ocular diagnoses. Participants with conditions such as glaucoma, although exhibit permanent vision loss, are often receiving treatment. These participants were categorised as “treatable”. The remaining sample with untreatable conditions such as RP were categorised as “untreatable”.

8.2.3 Results

Approximately half of the sample (n=26) reported registered sight loss, of which 69% (n=18) were registered severely sight impaired (Table 8.6). Only 3 participants with registered sight loss had a binocular VA worse than 6/60, suggesting that the remaining 23 registered participants were registered due to a restricted visual field, which is expected given the inclusion criteria for the study. One participant with visual fields restricted to within 15 degrees radius was not sight loss registered. Thirteen participants with registered sight loss had average visual field extents better than 15 degrees radius and a binocular VA better than 6/60. 65% of participants with “treatable” conditions were not certified as sight impaired, whereas 71% of those with “untreatable” conditions had registered their sight loss (Table 8.7). Almost all participants were aware of binocular visual field loss (92%), although 37% of those were not certified sight impaired (Table 8.8).

VA	VF extent	Sight loss registration			Total
		Not registered	Registered sight impaired	Registered severely sight impaired	
Better than 6/60	> 15 deg radius	21	5	6	32
Better than 6/60	< 15 deg radius	3	3	9	15
Worse than 6/60	> 15 deg radius	0	0	3	3
Worse than 6/60	< 15 deg radius	0	0	0	0
Total		24	8	18	50

Table 8.6 Cross table showing the showing the sight loss registration status of participants, and their degree of visual acuity and visual field loss.

Treatable ophthalmic diagnosis?	Sight loss registration			Total
	Not registered	Registered sight impaired	Registered severely sight impaired	
Treatable	17	4	5	26
Untreatable	7	4	13	24
Total	24	8	18	50

Table 8.7 Cross table showing the proportion of participants with treatable and untreatable disease, and their sight loss registration status

Are you aware of your VFL?	Sight loss registration			Total
	Not registered	Registered sight impaired	Registered severely sight impaired	
Yes	15	8	18	41
No	9	0	0	9
Total	24	8	18	50

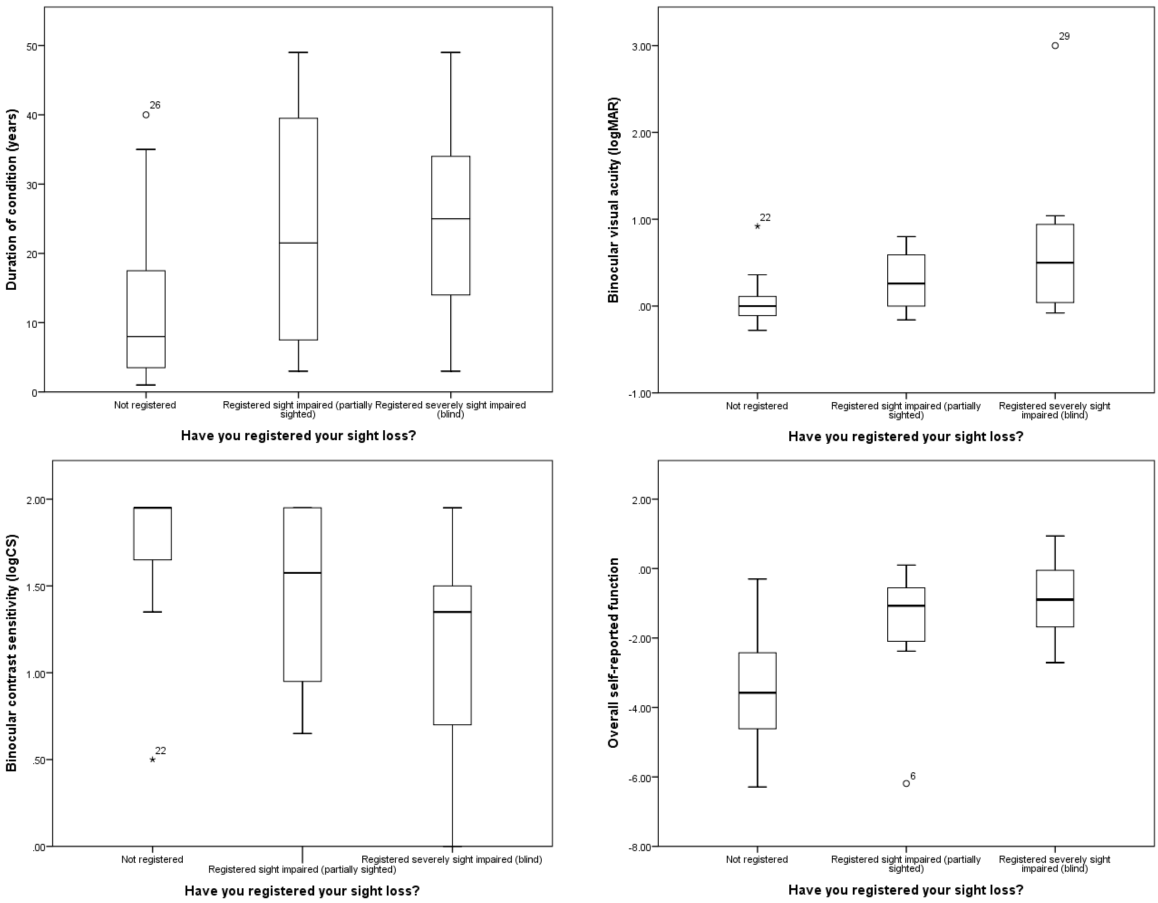
Table 8.8 Cross table showing the proportion of participants who were aware of their visual field loss, and their sight loss registration status

The relationship between sight loss registration and perceived and measured clinical function was explored. Participants registered as sight impaired or severely sight impaired reported greater duration of visual impairment, had worse binocular VA, binocular CS and visual field scores, and reported greater difficulty overall, and with mobility tasks than participants not registered visually impaired (Table 8.9, Figure 8.7).

Comparisons of these variables between different sight loss categories were made. Participants registered as sight impaired or severely sight impaired reported greater duration of visual impairment ($p<0.001$), worse self-reported function ($p<0.001$), and displayed worse visual function measures ($p<0.001$). However, when these variables were compared in participants who were registered as sight impaired and those registered severely sight impaired, no significant differences were found (Figure 8.7).

	Mann Whitney U	
	Not registered – Registered sight impaired or severely sight impaired	Registered sight impaired – Registered severely sight impaired
Duration of visual impairment (years)	U=144.51*	U=68.00
Binocular VA (LogMAR)	U=138.50*	U=49.00
Binocular CS (LogCS)	U=122.00*	U=52.50
Overall self-reported function	U=64.50*	U=57.00
Mobility self-reported function	U=64.00*	U=66.00
Binocular threshold VF score (dB)	U=106.00*	U=68.00
Binocular kinetic average field extent (deg)	U=89.00*	U=65.00

Table 8.9 Results of Mann Whitney U tests determining the differences between demographic and clinical function variables across sight loss registration categories (*p=<0.001, all others p≥0.001).



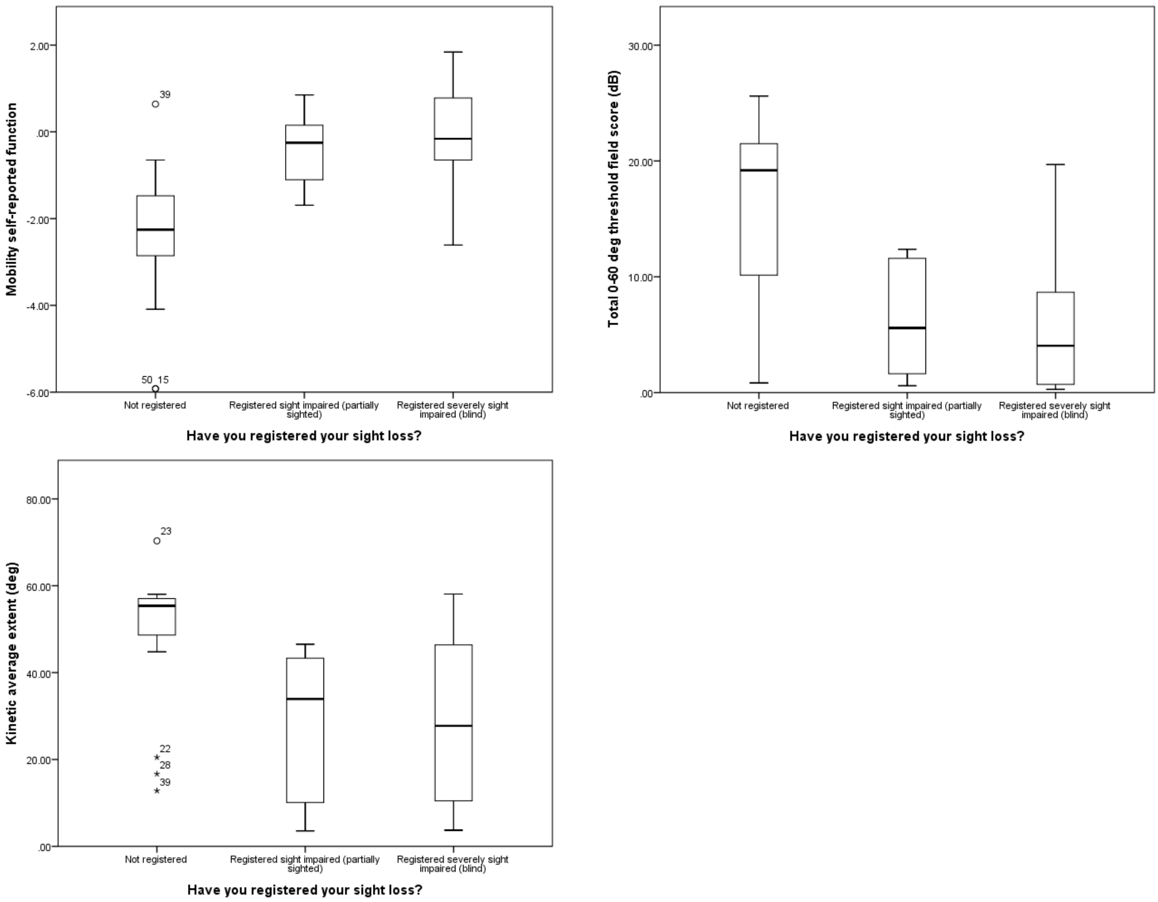
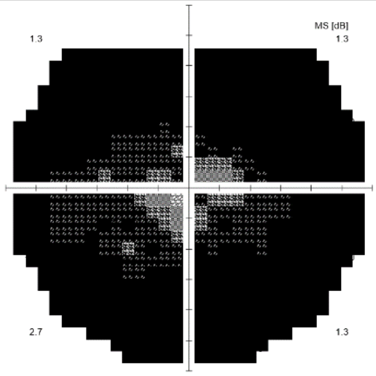


Figure 8.7 Box plot graphical representations of the association between demographic and clinical function variables and sight loss registration.

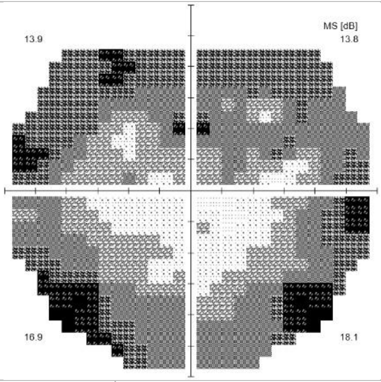
While all those with binocular VAs worse than 6/60 were registered as severely sight impaired, three participants with a visual field restricted to less than 15 degrees radius did not have their sight loss registered. A third of participants with a binocular VA better than 6/60, and a visual field extending at least 15 degrees radius were registered as sight impaired, or severely sight impaired. Some of these outlying cases are illustrated in Figure 8.8.

25



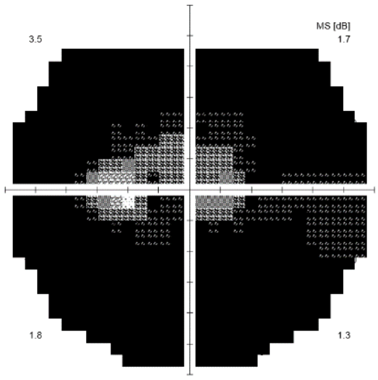
Binocular VA	0.92LogMAR
Binocular threshold score	1.69dB
Average VF extent	20.50 deg
Sight loss registration	Not registered
Ocular diagnosis	CRVO, glaucoma, retinal vasculitis

23



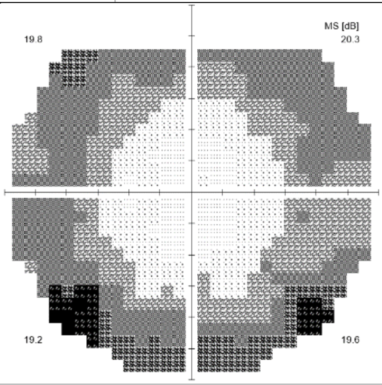
Binocular VA	0.04LogMAR
Binocular threshold score	15.76dB
Average VF extent	50.13 deg
Sight loss registration	Severely sight impaired
Ocular diagnosis	Glaucoma

31



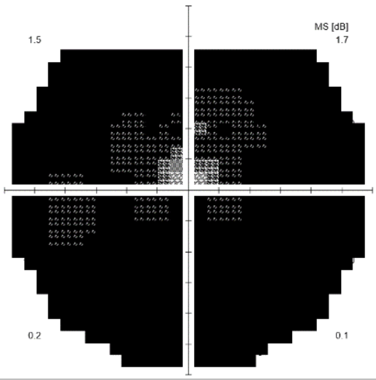
Binocular VA	0.08LogMAR
Binocular threshold score	2.06dB
Average VF extent	16.67 deg
Sight loss registration	Not registered
Ocular diagnosis	RP

38



Binocular VA	0.50LogMAR
Binocular threshold score	19.69dB
Average VF extent	55.17 deg
Sight loss registration	Severely sight impaired
Ocular diagnosis	Unknown retinal condition

42



Binocular VA	0.28LogMAR
Binocular threshold score	0.83dB
Average VF extent	12.79 deg
Sight loss registration	Not registered
Ocular diagnosis	RP

Figure 8.8 Outlying participants who met the criteria for sight loss registration, but who were not registered as visually impaired (participants 25, 31, and 42), and those who were registered as severely sight impaired despite not meeting sight loss registration criteria (participants 23 and 38).

8.2.4 Discussion

In the current study, participants with registered sight loss demonstrated advanced disease, well established vision loss, worse measured visual function, and worse perceived function.

While the duration of visual impairment, perceived function, and measured visual function varies in participants who are not sight loss registered when compared with those who have registered their sight loss, there appears to be no difference in these variables between the sight loss registration categories. Those registered as sight impaired reported a similar duration of impairment, similar degree of perceived function, and displayed similar degrees of loss in the visual function assessments. This suggests that current criteria for sight loss registration may not be helpful for ophthalmologists to identify the most appropriate visual impairment category for registration for their patients.

King et al., (2000) found that patients with reduced VA were more likely to be registered than those with restricted visual fields, or with loss in both VA and visual fields, reflecting the findings of this study where all participants with a binocular VA of 6/60 or worse were registered as severely sight impaired, but only 63% of those with a visual field restricted to 15 degrees radius or worse were registered as severely sight impaired. They also report that patients eligible for registration due to reduced VA were more likely to be registered early.

Almost 60% of their sample of glaucoma patients attending an outpatient clinic were not registered as sight impaired despite being eligible. Bunce et al., (1998) suggests that patients eligible for registration based on visual field loss are three times less likely that those with VA loss to be registered as sight impaired, and Guerin et al., (2014) reported very poor agreement among ophthalmologists in visual impairment registration of glaucoma patients with significant field loss. As shown in case studies presented in this chapter, King et al., (2000) suggest the under registration of eligible patients with visual field loss, and the delay in their registration compared to patients with VA loss could be because VA loss is "more obvious". Patients with restricted fields may retain good central vision, and so ophthalmologists may be slower to identify and register these patients. Furthermore, the visual field criteria used for visual impairment registration is open to significant subjective interpretation, with imprecisely defined categories such as "very restricted" and "gross defect" (Chapter 1), compared with objective criteria used for registration on the basis of reduced VA. Another cause for the inconsistency may arise from monocular presentation of visual field data, which requires the ophthalmologist to mentally combine the field data to construct a visual field plot which reflects patients' true binocular functional field (Guerin et al., 2014).

There were a small number of participants who were not registered as sight impaired, but whose visual field was severely constricted. One of these individuals (participant 42, Figure 8.8) had well established RP and had attended the hospital eye service annually, and yet remained unregistered since the issue of sight loss certification was never broached by consultants. Another participant (participant 25, Figure 8.8) reported an extensive history of ocular vascular incidents that had resulted in advanced vision loss, which although was permanent, the participant continued receiving treatment for underlying systemic conditions. It has been proposed that in patients with treatable diagnoses, registration is seen by ophthalmologists to be a last resort in the treatment of a visually impaired patient (King et al., 2000). Although a higher proportion of participants with untreatable conditions had registered sight loss in the current sample, this is likely due to those with treatable conditions, mainly glaucoma, exhibiting less severe field loss. The third unregistered participant with severely constricted visual fields (participant 31 Figure 8.8) remained so out of choice. This participant, who retained good central vision as indicated by their binocular VA, and continues to work full time, likely opposes registration since they feel they are able to continue functioning without need for extra support. Graham & Wallace (1968) however found that many patients eligible for registration opposed it because they felt it represented a form of charity.

Two participants (participants 23 and 38) exhibited good binocular VAs (0.50 and 0.04LogMAR respectively) and early to moderate visual field loss with field extent greater than 15 degrees radius, and yet both were registered as severely sight impaired. It has been suggested that ophthalmologists may be inclined to register patients as sight impaired even if they fail to meet registration criteria and therefore accelerate patients' access to support services if they felt assistance was warranted, while leaving other patients with significant field loss but with no perceived loss of quality of life unregistered (King et al., 2000).

8.2.5 Conclusion

Studies have demonstrated that a significant amount of unregistered sight loss exists amongst patients with visual field loss and treatable ophthalmic diagnoses. The relationship between sight loss registration status and measured and self-reported function has been demonstrated in this chapter. However, after comparing visual function results of the small sample of participants used in the current study against guidelines considered to represent current registration criteria, 10% may be either misclassified, or unclassified despite being eligible. An increased awareness of under registration, particularly in patients with treatable conditions and visual field loss, and more objective registration criteria needs to be considered to ensure patients receive an adequate level of support for their visual impairment. A functional visual field assessment, as defined in previous chapters could be used to develop evidence based criteria for visual impairment registration, including the level of visual field loss to quantify the boundaries of sight loss registration categories.

Chapter 9

Discussion and Conclusions

The aim of this study was to determine the most appropriate methods to assess functional visual fields in low vision patients. The Dutch Activity Inventory (D-AI) was chosen as the most appropriate method to assess overall self-reported function in both experiments, and the Independent Mobility Questionnaire was chosen to assess self-reported mobility function in Experiment 2 (Chapter 2). Both questionnaires demonstrated adequate psychometric properties in Chapter 3 and 5 respectively. A binocular threshold assessment out to 60 degrees determined areas of visual field that relate more effectively to self-reported function (Chapter 3). Alternative paradigms of visual field assessments were considered, and scores were derived and related to perceived function in Chapter 4. In Experiment 2, the visual field was assessed using three custom tests on the Octopus 900 and two existing tests on the Humphrey Field Analyser (Chapter 5). Visual field scores from these different assessments were also considered alongside the risk of falling (Chapter 7), patient acceptability, and sight loss registration (Chapter 8).

9.1 Visual field areas

Despite binocular visual field assessment representing functional abilities better than monocular assessment, especially in individuals with visual impairment (Nelson-Quigg et al., 2000; Schneck et al., 2010; Asaoka et al., 2011; Crabb et al., 2013), many previous studies that have related visual field loss to function used conventional monocular visual fields tests that do not reflect the binocular field (Gutierrez et al., 1997; Parrish et al., 1997; Szlyk et al., 1997;1998; Nelson et al., 1999; Turano et al., 2004; Varma et al., 2006; Seo et al., 2009; El Gasim et al., 2013), or assessed the visual field using monocular threshold tests to construct a binocular field plot (Crabb & Viswanathan 2004; Aspinall et al., 2008). Of the studies that have assessed the visual field binocularly, the majority have assessed the visual field out to 30 degrees (Black et al., 1996; Tabrett & Latham 2012). Those studies that have assessed the binocular visual field past 30 degrees have used kinetic (Turano et al., 1999; Lovie-Kitchin et al., 1999; Haymes et al., 2000; 2002; Hassan et al., 2007) or suprathreshold threshold test strategies such as the Esterman visual field test (Mills et al., 1986; Jampel et al., 2002a; 2002b; Noe et al., 2003; Fuijita et al., 2008). No other study has determined the binocular threshold sensitivity of the visual field past 30 degrees eccentricity.

In the present study, binocular functional fields have been assessed in patients with peripheral visual impairment by implementing conventionally monocular central threshold static perimetry test programs, namely the central 30-2 and 60-4 tests, binocularly as demonstrated in Chapter 3. While few studies have demonstrated the use of a conventional monocular test binocularly to assess the central 24 or 30 degrees of the visual field (Black et al., 1996; Leat & Lovie-Kitchin, 2010; Tabrett & Latham, 2012), the present study is the first to implement a monocular peripheral examination of the visual field binocularly. The mean threshold of the binocular visual field to 60 degrees eccentricity can represent the functional abilities of individuals with peripheral visual impairment (Chapter 3).

This relationship between the overall visual field and self-reported function does not appear to be greatly dependent on eccentricity out to 60 degrees. The central and peripheral visual field scores are similarly related to perceived function suggesting that both areas are important to assess when considering functional ability. However it was the peripheral (30-60 deg) field that was selected as the best predictor of both overall and mobility related self-reported function in multiple regression analyses, suggesting that in order to accurately determine the functional consequences of visual field loss, the peripheral visual field should not be ignored. This reflects the findings of other studies that also report the importance of the peripheral visual field to mobility function (Marron & Bailey, 1982; Geruschat et al., 1998; Turano et al., 2004; Freeman et al., 2007; Patino et al., 2010).

The inferior and superior visual field areas were also similarly related to mobility related perceived function, although in multiple regression analysis the inferior visual field was found to predict self-reported mobility difficulty better than the superior visual field, suggesting the importance of the inferior visual field to mobility function that has been documented in several studies (Lovie-Kitchin et al., 1990; Turano et al., 2004; Coleman et al., 2007; Black et al., 2008; Marigold & Patla, 2008; Black et al., 2011), but disputed in others (Freeman et al., 2007; Tabrett & Latham, 2012). As discussed in Chapter 3, previous studies demonstrating the importance of the inferior visual field for mobility function have assessed subjects whose degree of visual field loss was likely less than that of many of the participants in the current study. These studies have evaluated older adults with no visual impairment (Turano et al., 2004; Coleman et al., 2007), normally sighted subjects with simulated field loss (Marigold & Patla, 2008), participants with glaucoma (Black et al., 2008;2011), and a mixed sample with half the participants having visual impairment (Lovie-Kitchin et al., 1990). To investigate if the relationship between the superior and inferior areas of the visual field and self-reported mobility function varies with the degree of visual field loss, the sample was split into participants with an overall visual field score of ≥10dB (n=27), and participants with an overall field score of <10dB (n=25). The relationship between the superior visual field and self-reported mobility function lost its statistical significance in participants with better visual fields. In this group of participants in a multiple regression analysis, the inferior visual field was selected as the greatest predictor of perceived mobility function. This is unlike the group of participants with worse overall visual fields. The superior and inferior visual field areas in this group were similarly related to mobility function, and binocular CS was selected as the greatest predictor of self-reported mobility function in a multiple regression analysis. While the inferior field bias has been investigated in patients with little or no visual field impairment, in the present study it is demonstrated that loss in the inferior visual field remains a better indicator of perceived mobility function than the superior field in individuals with a greater degree of established visual impairment, but not for those with greatest loss.

Further to this, while the association between the inferior visual field and mobility is well documented, the significance of the inferior visual field to overall function has not previously been investigated. As demonstrated in Chapter 3, the inferior visual field was also selected as the primary predictor of overall perceived function, indicating the significance of the inferior visual field for general function. This could be explained by the presence of more ecologically relevant information in this region of space (Rezac & Dobkins, 2004).

The visual field was assessed using different paradigms in Chapter 5, and scores were determined for different areas of the visual field for all assessments. These results were presented in Chapter 6. Reflecting the results from Experiment 1, both the central and peripheral visual field areas, assessing using binocular threshold, binocular suprathreshold, and Esterman tests related well to self-reported function. The peripheral visual field was slightly more strongly correlated to perceived function however, and was selected as the best predictor of both overall and mobility self-reported function for binocular threshold and Esterman assessments in multiple regression analyses, indicating the importance of assessing the visual field past 30 degrees eccentricity when considering functional abilities of patients with visual impairment. The inferior visual field was selected as the primary predictor of mobility function in multiple regression analyses for all visual field assessments. A further analysis involving the plotting of ROC curves suggested that the inferior visual field was better than the superior field at correctly identifying participants who reported difficulties with certain mobility tasks.

9.2 Visual field paradigms

Several studies have investigated the ability of currently available visual field assessments, namely the Esterman assessment, and monocular threshold tests or the IVF, at predicting functional ability of patients with visual impairment (Crabb & Viswanathan, 2004; Sumi et al., 2003; Jampel et al., 2002a). Jampel et al., (2002a) created custom suprathreshold assessment to investigate if altering the stimulus intensity of the Esterman would increase its range of scores, and compared results with IVF. There is no known study that evaluates visual field paradigms and their ability to assess functional ability more broadly.

Using data collected from Experiment 1, suprathreshold and kinetic field scores were derived from the threshold data as described in Chapter 4. All three methods of derivation related similarly to self-reported function, and each explained a similar degree of variance in self-reported function in multiple regression analyses. This indicated that little information may be lost by using a quicker assessment paradigm such as suprathreshold or kinetic, over a threshold assessment.

To investigate further the most appropriate method of assessing the functional visual field in individuals with low vision, different visual field assessments were performed and scores were related to self-reported function in Chapter 5. Results from Experiment 1 influenced the protocol of visual field assessments used in Experiment 2. Assessing the visual field binocularly using a threshold test strategy represented the functional abilities of patients with visual impairment (Chapter 3). Other studies have suggested the ideal functional visual field assessment would incorporate a binocular threshold test with the wide testing area of the Esterman has been suggested by others (Turano et al., 1999; Jampel et al., 2002a). It was also concluded in Chapter 3 that to represent the functional abilities of patients with visual impairment, the peripheral visual field needs to be considered. Since an ideal functional visual fields test may be dependent on a patient's degree of residual visual field, despite the inferior field bias demonstrated in the data, an ideal visual field test for a general low vision population will weigh the superior and inferior field areas similarly since it may be dependent on the degree of visual field loss.

Three custom visual field assessments were designed on the Octopus 900 perimetry for Experiment 2. All three of these assessments were binocular and assessed the visual field to 60 degrees from fixation. The only existing binocular functional visual fields assessment, the Esterman test, and current gold standard functional field assessment in the UK, the IVF, were also performed.

While all five visual fields assessments relate similarly to perceived function, the three custom tests, and the Esterman explained a greater degree of variance in self-reported mobility function in multiple regression analyses, and produced statistically significant greater areas under the curves in ROC analyses. The IVF score accounted for the smallest proportion of variance in perceived function in multiple regression analysis when compared with the other visual field assessments, and ROC analysis indicated it was not as effective as other assessments at correctly identifying participants with perceived difficulty with mobility tasks. Therefore, the paradigm used to assess the visual field (threshold or suprathreshold static, or kinetic) makes little difference to the relationship with function: so long as the test is performed binocularly and includes assessment of eccentricities to 60 deg, the visual field outcome measure reflects self-reported function well.

Consistent with findings of previous studies, the IVF related to mobility function (Aspinall et al., 2008; Black et al., 2011). Contrary to other studies however (Jampel et al., 2002a; Crabb & Viswanathan, 2004), the IVF appeared to be less effective at relating to self-related mobility function when compared to the Esterman assessment. This may be due to the difference in the degree of visual field loss between the sample groups. The average Esterman scores in the current study (56.4%) is less than the average scores (87.4% and 86.7%) reported in the other studies, and would suggest a sample with greater degree of visual field loss.

Tests that are quicker to perform, namely the binocular suprathreshold and binocular kinetic assessments related just as well to self-reported function as tests that took longer such as the binocular threshold assessment. Reflecting the preliminary analysis of derived scores in Chapter 4, data from Experiment 2 indicated that functional information is not lost by using a kinetic or suprathreshold techniques when compared to the diagnostic gold standard of measuring static thresholds.

9.3 Falling

Despite the association between visual field loss and the risk of falling being reported in several studies (Jack et al., 1995; Klein et al., 1998; Ivers et al., 1999; Ramrattan et al., 2001; Freeman et al., 2007; Patino et al., 2010), no significant association was found in the present study. In

Experiment 1, there was no significant difference in any of the visual field areas between participants who reported a fall, and those who had not (Chapter 3).

The Falls Efficacy Scale (FES-I) was used in Experiment 2, as described in Chapter 5 to investigate the relationship between the fear of falling and visual field loss. The relationship between the fear of falling and fall frequency is noted in several studied (Howland et al., 1993; Tinetti et al., 1994; Arfken et al., 1994; Fessel and Nevitt, 1997; Howland et al., 1998; Lachman et al., 1998), and the FES-I has been shown to be more sensitive at assessing the fear of falling compared with other measures (Tinetti et al., 1990; T inetti et al., 1994; Myers et al., 1996).

As outlined in Chapter 7, although fall history was not significantly associated with any visual field variable in either of the experiments, the visual field assessed using a custom binocular kinetic test and Esterman assessment related to fear of falling, with participants with greater field loss reporting greater fear of falling. These findings are consistent with other studies (Ramulu et al., 2012; Yuki et al., 2013). Binocular threshold scores for different areas of the visual field were related to the FES-I person measures to further investigate the relationship between the visual field and the fear of falling. The binocular threshold peripheral field score significantly related to fear of falling while the central field score did not. While the binocular threshold superior score was not significantly related to fear of falling, a significant relationship was found between fear of falling and the inferior field score. These findings reflect the findings of Chapter 3 and 6 that highlight the importance in particular of the peripheral and inferior visual field to perceived function.

Falls have multifactorial and interacting predisposing causes, and retrospective recall of falls is unreliable (Cummings et al., 1988). The fear of falling is easier for patients, especially elderly patients, to report (Yardley et al., 2002), and may relate better to clinical measures of function.

9.4 Patient acceptability

While Gardiner & Demirel (2008) and Glen et al., (2014) assessed patients' opinions of different clinical tests used in the management of glaucoma, including the visual field assessment, patients' views on specific visual field paradigms have not been reported previously.

Patient input is important to help devise optimal strategies for functional field assessment since visual field testing can be exhausting for patients (Gardiner & Demirel, 2008), and testing of prolonged duration can result in fatigue affecting visual field results (Hudson et al., 1994), and difficulty maintaining concentration (Henson & Emuh, 2010). Results outlined in Chapter 5 showed that all binocular assessments of the visual field out to 60 degrees are similarly effective are predicting perceived disability in patients with peripheral field loss. Of the five visual field tests performed, the Esterman assessment took longer in participants with greater visual field loss, was ranked poorly for patient acceptability, and produced the least favourable test output, suggesting its unsuitability for functional field determination in individuals with low vision. The binocular threshold assessment, although producing outputs that were familiar, reflecting the visual field binocularly, and illustrating the peripheral field, took a long time to perform. Similarly, the IVF is long and demanding for participants, many of whom found the monocular assessment more difficult than binocular testing. Shorter novel visual field tests like the binocular suprathreshold, and in particular the kinetic assessment used in this study are favoured by participants.

A quick test is likely to be less influenced by fatigue and to be preferable, and as illustrated in the current study, can provide the same level of functional information as a longer threshold examination. The kinetic test was ranked most favourably by about half of the participants. In addition to being quick to perform, the Riddoch phenomenon means that detection of a moving stimulus is easier than for a static stimulus (Hudson et al., 1994; Zeki & FFytche, 1998), and this may be more evident in defective regions of the visual field (Safran & Glaser, 1980). The kinetic assessment is also quite novel compared with the currently more usual static paradigms, and this novelty could improve vigilance and performance (Henson & Emuh, 2010).

9.5 Sight loss registration

Studies have demonstrated that a significant amount of unregistered sight loss exists amongst patients with visual field loss and treatable ophthalmic diagnoses (Robinson et al., 1994; Bunce et al., 1998; King et al., 2000; Barry & Murray, 2005). The relationship between sight loss registration status and visual field loss was investigated in Chapter 8. After comparing visual function results of the small sample of participants used in the present study against guidelines considered to represent current registration criteria, 10% of participants were either misclassified, or unclassified despite being eligible. An increased awareness of under registration, particularly in patients with treatable conditions and visual field loss, and more objective registration criteria needs to considered to ensure patients receive an adequate level of support for their visual impairment. A functional visual field assessment, as defined in previous chapters could be used to develop evidence based criteria for visual impairment registration, including the level of visual field loss to quantify the boundaries of sight loss registration categories.

9.6 Ideal functional visual field assessment

The properties of an ideal visual field test for the assessment of functional ability were outlined in Chapter 1. It is proposed in the present study that a binocular visual field assessment that utilises a suprathreshold or kinetic paradigm, and that assesses the visual field to 60 degrees is effective at reflecting the functional abilities of patients with peripheral visual impairment. Such a visual field test reflects binocular function, and has been shown to relate well to self-reported visual difficulty, and differentiate between people with different levels of perceived difficulty and clinical function measures. Both the custom binocular suprathreshold and kinetic visual field assessments were quick and acceptable to patients. The proposed visual field assessment can be created as a custom assessment on both the Octopus 900 and Humphrey Field Analyser. Regarding the output of the assessments, all participants understood the binocular kinetic and binocular suprathreshold field results after having them explained. Care must be taken however to ensure that suprathreshold test points are large enough for patients with visual impairment to see.

9.7 Limitations

Participation in this study was entirely voluntary, and the sample may exhibit higher levels of conscientiousness than the general population due to response bias. However, as the descriptive statistics in Chapters 3 and 5 illustrate, the range of peripheral visual field loss represented in the sample was wide, and participants reported a wide variation in levels of ability.

Functional ability is intertwined with other factors as discussed in Chapter 2, and therefore self-reported visual function may not accurately reflect actual visual function. Self-reported instruments however can take into account the relevance of particular tasks, and can assess a wide range of activities, unlike objective measures of mobility performance that only provide evidence of the specific capabilities measured. Avoiding the practical difficulties involved in devising an appropriate performance assessed measure outlined in Chapter 2, self-report methods rather than objective assessment were used in the present study to reflect functional ability in general.

Another limitation of the study is the relatively small sample size. The sample size prevented further evaluation of the relationship between perceived function and smaller, more precise areas of the visual field. However, the sample size is adequate for a study of the validity of previously unused binocular visual field assessments. The sample size also reflects the size of participant groups in similar studies (Turano et al., 1999; Bibby et al., 2007; Lee et al., 2013). Furthermore, a post-hoc analysis to determine the power of the study based on the sample size used, and the effect size calculated was undertaken. Statistical power (1-α) computed as a function of significance level (α 0.05), sample size (50), and population effect size (R^2=0.40) using G*Power software (Faul et al., 2007) suggests a large statistical power (1-α=0.99989), and a sufficient large sample size.

Binocular threshold sensitivities of the visual field were determined as outlined in Chapter 3 and 5. It should be noted that testing of visual field locations that have sensitivities of below 15dB may be unreliable, and threshold testing of these areas does not produce reliable threshold estimates (Gardiner et al., 2014). Limited information can still be collected from testing these locations however. A measured threshold sensitivity of >15dB indicates that some function remains at that location, even if threshold values cannot be reliably determined. Furthermore, Artes et al., (2002) reports a positive correlation exists between repeated measurements of visual fields locations with low sensitivity.

To produce visual field results comparable to the custom binocular threshold and suprathreshold assessments in Chapter 5, kinetic stimuli in the custom binocular kinetic assessment were presented from 60 degrees eccentricity. To determine a more accurate indication of patients' residual visual field extent, kinetic stimuli must be presented well outside the normal range of visibility however. Furthermore, since this study presented an initial investigation of validity of previously unused binocular visual field assessments, no repetitions were undertaken of vectors in the kinetic assessment. Numerous repetitions of vectors are required to determine the reliability of responses, and to avoid "spurious spikes" described by Lynn et al., (1990). Although kinetic perimetry requires individual tailoring to ensure accuracy (Rowe & Rowlands, 2014), it has been demonstrated in the present study that an isopter plotted using single vector presentations can provide an accurate indication of self-reported function, and a global measure that correlates highly with other more comprehensive measures of the visual field. Finally the ability of a kinetic assessment to reliably determine a score for visual fields that falls within the central 10 degrees of fixation is not known. In the present study however, participants with a range of visual field loss were assessed, including those with advanced field restriction.

In considering the repeatability and reliability of these assessments, it is proposed that while functional visual fields described in this study test may not plot the field precisely, they are able to provide valuable functional information in difficult to assess patients.

9.8 Conclusions

The present study has determined that:

- In order to accurately determine the functional consequences of visual field loss, it is necessary to assess beyond 30 degrees.
- The inferior visual field is a better indicator of perceived mobility function than the superior field. The inferior visual field is more important than the superior field for general function.
- Assessing the visual field binocularly using a custom threshold, suprathreshold, and kinetic test strategy can represent the functional abilities of people with visual impairment.
- As long as the test is performed binocularly and includes assessment of eccentricities to 60 degrees, the paradigm used to assess the visual field (threshold or suprathreshold static, or kinetic) makes little difference to the assessment's ability to predict function. Quick tests using a kinetic or suprathreshold paradigm are more favoured by patients however.

9.9 Future research

The visual field in the present study was considered to 60 degrees from fixation. Further research may wish to investigate how the field past 60 degrees eccentricity relates to functional ability.

Self-reported measures of function were used in this study. The visual field assessments presented in this study could be related to objectively assessed performance.

Although Wang & Henson (2013) investigated the effect of reducing the number of test locations on a visual field test's sensitivity and specificity at identifying disease, it is not known whether a reduced number of test points in a binocular suprathreshold assessment would influence its ability to predict functional ability. Further research may wish to investigate this.

The repeatability of binocular visual field assessment could be investigated, including binocular threshold sensitivities, and visual field extent, in particular within the central 10 degrees from fixation.

While a preliminary analysis of data in Experiment 2 using derived suprathreshold scores from a range of stimulus intensities suggests that all derived scores are similarly effective at predicting self-reported function, this could be investigated further with measured suprathreshold assessment at different stimulus intensities.

Experiment 1 data suggested that the ideal functional visual fields test for the low vision assessment may be dependent on the patient's degree of residual visual field. Further research may investigate the feasibility of a two-step test that first determines the degree of residual vision.

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Appendices

Appendix 1: Self-reported instruments used

A1.1 List of 12 common medical conditions described by van Nispen et al., (2008).

Diabetes
COPD or asthma
Heart
Stroke
Hearing impairments
Musculo-skeletal
Cancer
Hypertension
Thyroid gland
Chronic allergies
Gastrointestinal
Chronic skin problems
Psychological problems

A1.2 Dutch ICF Activity Inventory domains and goals (Bruijning et al., 2010;2013).

Chapter	Domain (ICF 'Activities and Participation')	Number of goals	Total number of tasks	Number of tasks	Goal
1	Learning and applying knowledge	3	29	13	Reading
				6	Writing
				10	Watching TV
2	General tasks and demands	2	16	10	Personal administration
				6	Follow a schedule
3	Communication	3	38	23	Using computer at home
				8	Personal correspondence
				7	Using telephone
4	Mobility	8	140	9	Mobility at home
				11	Mobility indoors somewhere else
				22	Walking outdoors
				24	Driving a vehicle for disabled people
				17	Riding a bike
				17	Riding a motorised bike/moped/scooter
				24	Driving a car
				16	Using public transportation
5	Self-care	5	76	13	Dressing
				20	Personal hygiene
				8	Using a public toilet
				24	Personal heath care
				11	Eating and drinking
6	Domestic life	12	166	16	Household tasks
				8	Doing laundry
				11	Doing chores at home
				6	Mending clothes
				9	Withdraw or dealing with money
				27	Daily shopping
				28	Daily meal preparation
				9	Guide dog care
				12	Pet care
				4	Shopping
				21	Health care for an adult
				15	Child care
7	Interpersonal interactions and relationships	6	57	16	Recognition and communication
				8	Interaction with partner
				8	Interaction with family
				4	Interaction with relatives and friends
				15	Interaction with colleagues
				6	Interaction with strangers
8	Major life areas	9	97	13	Manage finance
				4	Manage difficult financial situations
				8	Regulatory and information
				12	Education
				5	Apply for a job
				9	Accessibility at work
				12	Working activities
				22	Using computer at work
				12	Attend meetings

9	**Community, social, and civic life**	12 5	137 22	16	Follow the news
				11	Intellectual activities
				17	Having visitors
				24	Social events
				19	Dining out
				3	Social activities and trips
				14	Going on holiday
				12	Gardening
				4	Making music
				4	Perform in public
				7	Watching TV or movies (recreational)
				6	Using specific ICT tools
				5	Attend cultural event#
				2	Playing games#
				1	Creative activities#
				6	Hobbies and crafts#
				8	Play sports#
10	**Mental (emotional) health Aspects***	3	35	9	Feeling fit
				11	Handle feelings
				15	Acceptance
	TOTAL	68	813	813	

A1.3 Part 2 of the Independent Mobility Questionnaire (Turano et al., 1999).

Name: ______________________ Date: ______________________ D.O.B.:______________________

List 3 things that cause you the most stress in your mobility situations (walking around):

______________________ ______________________ ______________________

Directions: Read each mobility situation given below and circle the number which best expresses the level of difficulty you feel in the situation without any assistance (cane, companion, guide dog, etc). On a scale of 1 to 5, 1 represents no difficulty and 5 represents extreme difficulty. N/A represents not applicable. Use N/A also if you only perform an activity with assistance. If your selection is greater than 1 and the difficulty is due to some reason other than your vision loss, please place an "x" in the blank space.

Walking in familiar areas	N/A	1	2	3	4	5	___
Walking in unfamiliar areas	N/A	1	2	3	4	5	___
Moving about in							
Home	N/A	1	2	3	4	5	___
Work	N/A	1	2	3	4	5	___
Classroom	N/A	1	2	3	4	5	___
Stores	N/A	1	2	3	4	5	___
Outdoors	N/A	1	2	3	4	5	___
Moving about in crowded situations	N/A	1	2	3	4	5	___
Walking at night	N/A	1	2	3	4	5	___
Using public transportation	N/A	1	2	3	4	5	___
Detecting ascending stairwells	N/A	1	2	3	4	5	___
Detecting descending stairwells	N/A	1	2	3	4	5	___
Walking up steps	N/A	1	2	3	4	5	___
Walking down steps	N/A	1	2	3	4	5	___
Stepping onto curbs	N/A	1	2	3	4	5	___
Stepping off curbs	N/A	1	2	3	4	5	___
Walking through doorways	N/A	1	2	3	4	5	___
Walking in high-glare areas	N/A	1	2	3	4	5	___
Adjusting to lighting changes during the day							
Indoor to outdoor	N/A	1	2	3	4	5	___
Outdoor to indoor	N/A	1	2	3	4	5	___
Adjusting to lighting changes at night:							
Indoor to streetlights	N/A	1	2	3	4	5	___
Streetlights to indoor	N/A	1	2	3	4	5	___
Walking in dimly lit indoor areas	N/A	1	2	3	4	5	___
Being aware of another person's presence	N/A	1	2	3	4	5	___
Avoiding bumping into:							
People	N/A	1	2	3	4	5	___
Walls	N/A	1	2	3	4	5	___
Head-height objects	N/A	1	2	3	4	5	___
Shoulder-height objects	N/A	1	2	3	4	5	___
Waist-height objects	N/A	1	2	3	4	5	___
Knee-height objects	N/A	1	2	3	4	5	___
Low-lying objects	N/A	1	2	3	4	5	___
Avoiding tripping over uneven travel surfaces	N/A	1	2	3	4	5	___
Moving around in social gatherings	N/A	1	2	3	4	5	___
Finding restrooms in public places	N/A	1	2	3	4	5	___
Seeing cars at intersections	N/A	1	2	3	4	5	___

A1.4 Falls Efficacy Scale-International (Yardley et al., 2005).

Now we would like to ask some questions about how concerned you are about the possibility of falling. Please reply thinking about how you usually do the activity. If you currently don't do the activity (e.g. if someone does your shopping for you), please answer to show whether you think you would be concerned about falling IF you did the activity. For each of the following activities, please tick the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.					
		Not at all concerned 1	*Somewhat concerned 2*	*Fairly concerned 3*	*Very concerned 4*
1	Cleaning the house (e.g. sweep, vacuum or dust)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
2	Getting dressed or undressed	*1* ☐	*2* ☐	*3* ☐	*4* ☐
3	Preparing simple meals	*1* ☐	*2* ☐	*3* ☐	*4* ☐
4	Taking a bath or shower	*1* ☐	*2* ☐	*3* ☐	*4* ☐
5	Going to the shop	*1* ☐	*2* ☐	*3* ☐	*4* ☐
6	Getting in or out of a chair	*1* ☐	*2* ☐	*3* ☐	*4* ☐
7	Going up or down stairs	*1* ☐	*2* ☐	*3* ☐	*4* ☐
8	Walking around in the neighbourhood	*1* ☐	*2* ☐	*3* ☐	*4* ☐
9	Reaching for something above your head or on the ground	*1* ☐	*2* ☐	*3* ☐	*4* ☐
10	Going to answer the telephone before it stops ringing	*1* ☐	*2* ☐	*3* ☐	*4* ☐
11	Walking on a slippery surface (e.g. wet or icy)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
12	Visiting a friend or relative	*1* ☐	*2* ☐	*3* ☐	*4* ☐
13	Walking in a place with crowds	*1* ☐	*2* ☐	*3* ☐	*4* ☐
14	Walking on an uneven surface (e.g. rocky ground, poorly maintained pavement)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
15	Walking up or down a slope	*1* ☐	*2* ☐	*3* ☐	*4* ☐
16	Going out to a social event (e.g. religious service, family gathering or club meeting)	*1* ☐	*2* ☐	*3* ☐	*4* ☐

A1.5 Adelaide Activities Profile (Bond and Clark, 1998).

1) How often have you prepared a main meal?
   Never   Less than once a week   1 to 2 times a week   Most days
2) How often have you washed the dishes?
   Less than once a week   1 or 2 days a week   Most days   Every day
3) How often have you washed clothes?
   Never   About once a month   About once a fortnight   Once a week or more
4) How often have you done light housework?
   Never   Once a fortnight or less   About once a week   Several days a week
5) How often have you done heavy housework?
   Never   About once a month   About once a fortnight   Once a week or more
6) How many hours of voluntary or paid employment have you done?
   None   Up to 10 hours a week   10 to 30 hours a week   More than 30 hours a week
7) How often have you cared for other family members?
   Never   About once a month   About once a fortnight   Once a week or more
8) How often have you done household shopping?
   Never   About once a month   About once a fortnight   Once a week or more
9) How often have you done personal shopping?
   Never   Once in 3 months   About once a month   Once a fortnight or more
10) How often have you done light gardening?
    Never   About once a month   About once a fortnight   Once a week or more
11) How often have you done heavy gardening?
    Never   About once a month   About once a fortnight   Once a week or more
12) How often have you done household and/or car maintenance?
    Never   Once in 3 months   About once a month   Once a fortnight or more
13) How often have you needed to drive a car or organize your own transport?
    Never   Up to once a month   Up to once a fortnight   Once a week or more
14) How often have you spent some time on a hobby?
    Never   About once a month   About once a week   More than once a week
15) How many telephone calls have you made to friends or family?
    None   Up to 3 calls a week   4 to 10 calls a week   Over 10 calls a week
16) How often have you invited people to your home?
    Less than once a fortnight   About once a fortnight   About once a week   More than once a week
17) How often have you participated in social activities at a centre such as a club, a church, or a community centre?
    Less than once a month   About once a month   About once a week   More than once a week

18) How often have you attended religious services or meetings?

Never | About once a month | About once a fortnight | Once a week or more

19) How often have you participated in an outdoor social activity?

Never | About once a month | About once a fortnight | Once a week or more

20) How often have you spent some time outdoors participating in a recreational or sporting activity?

Never | About once a month | About once a week | More than once a week

21) How often have you walked outdoors for 15 minutes or more?

About once a month or less | About once a fortnight | About once a week | Most days

All questions are scored 0, 1, 2 or 3. Detailed notes on the definition of each activity and complete instructions for administration are available on request from the authors. Reproduced with permission from Clark and Bond. The Adelaide Activities Profile: A measure of the lifestyle activities of elderly people *Aging Clin Exp Res* 1995; **7**: 174–84.

Appendix 2: Raw data

A2.1 Descriptive statistics of the ordinal D-AI scores (Chapter 1).

	Mean (±std)	**Median (25% IQ-75% IQ))**
Domain 1: Learning and Applying Knowledge	2.10(±0.15)	1.67(1.33-2.67)
How important/difficult is it for you to be able to read?	2.17(±0.16)	2.00(1.00-3.00)
How important/difficult is it for you to be able to write?	2.10(±0.10)	1.50(1.00-3.00)
How important/difficult is it for you to be able to watch TV?	2.02(±0.17)	2.00(1.00-2.25)
Domain 2: General Tasks and Demands	1.84(±0.14)	1.50(1.00-2.50)
How important/difficult is it for you to be able to take care of your personal administration without someone else's assistance? (e.g. read post, write/type letters, fill in forms)	2.10(±0.19)	1.00(1.00-3.00)
How important/difficult is it for you to follow a schedule without someone else's assistance (e.g. getting to your appointment in time)?	1.58(±0.15)	1.00(1.00-2.00)
Domain 3: Communication	1.56(±0.10)	1.17(1.00-2.00)
How important/difficult is it for you to be able to use a computer without someone else's assistance?	1.60(±0.13)	1.00(1.00-2.00)
How important/difficult is it for you to be able to take care of your personal correspondence without someone else's assistance?	1.69(±0.16)	1.00(1.00-2.00)
How important/difficult is it for you to be able to use your telephone without someone else's assistance?	1.31(±0.10)	1.00(1.00-1.00)
Domain 4: Mobility	2.14(±0.13)	2.25(1.25-2.81)
How important/difficult is it for you to be able to move around in your home, without someone else's assistance?	1.41(±0.08)	1.00(1.00-2.00)
How important/difficult is it for you to be able to move around indoors in unfamiliar surroundings, without someone else's assistance?	2.50(±0.17)	2.5(1.00-3.00)
How important/difficult is it for you to be able to move/walk around outdoors without someone else's assistance?	2.37(±0.17)	2.00(1.00-3.00)
How important/difficult is it for you to be able to use public transportation?	2.27(±0.18)	2.00(1.00-3.00)
Domain 5: Self-Care	1.19(±0.05)	1.00(1.00-1.25)
How important/difficult is it for you to be able to dress yourself without someone else's assistance?	1.19(±0.07)	1.00(1.00-1.00)
How important/difficult is it for you to be able to take care of your personal hygiene, without someone else's assistance?	1.10(±0.04)	1.00(1.00-1.00)

How important/difficult is it for you to be able to look after your own health?	1.21(±0.07)	1.00(1.00-1.00)
How important/difficult is it for you to be able to eat and drink without someone else's assistance?	1.25(±0.09)	1.00(1.00-1.00)
Domain 6: Domestic Life	1.94(±0.13)	1.89(1.07-2.39)
How important/difficult is it for you to clean and tidy up the house, without someone else's assistance?	1.73(±0.12)	2.00(1.00-2.00)
How important/difficult is it for you to do the laundry without someone else's assistance?	1.49(±0.15)	1.00(1.00-2.00)
How important/difficult is it for you to do chores at home without someone else's assistance? (e.g. tightening a screw, painting, carrying out general maintenance tasks around the home)	2.39(±0.20)	2.00(1.00-3.00)
How important/difficult is it for you to mend your clothes?	2.31(±0.27)	2.5(1.00-3.00)
How important/difficult is it for you to withdraw money and pay, without someone else's assistance?	1.69(±0.17)	1.00(1.00-2.00)
How important/difficult is it for you to do your daily shopping, without someone else's assistance?	2.06(±0.18)	2.00(1.00-2.75)
How important/difficult is it for you to shop (other than groceries) without someone else's assistance?	2.27(±0.19)	2.00(1.00-3.00)
How important/difficult is it for you to prepare your daily meal, without someone else's assistance?	1.84(±0.18)	1.00(1.00-2.75)
How important/difficult is it for you to provide an adult with health care without someone else's assistance?	1.54(±0.27)	1.00(1.00-2.00)
How important/difficult is it for you to look after young (grand) children, without someone else's assistance?	2.04(±0.23)	2.00(1.00-3.00)
How important/difficult is it for you to take care of your pet or guide dog without someone else's assistance?	1.56(±0.20)	1.00(1.00-2.00)
Domain 7: Interpersonal Interactions and Relationships	1.66(±0.10)	1.42(1.00-2.25)
How important/difficult is it for you to be able to communicate with people?	1.58(±0.12)	1.00(1.00-2.00)
How difficult is your relationships with your loved ones because of your visual impairment?	1.46(±0.10)	1.00(1.00-2.00)
How difficult is the relationships with your colleagues because of your visual impairment?	1.82(±0.17)	1.00(1.00-3.00)
How difficult is your relationships with people you don't know because of your visual impairment?	1.90(±0.16)	1.00(1.00-3.00)
Domain 8: Major Life areas	1.86(±0.12)	1.68(1.00-2.43)
How important/difficult is it for you to manage your finance without someone else's assistance?	1.58(±0.16)	1.00(1.00-1.25)
How important/difficult is it for you to get information (e.g. regulatory or information concerning your eye condition) without someone else's assistance?	1.62(±0.16)	1.00(1.00-2.00)
How important/difficult is it for you to be able to follow education or courses?	2.13(±0.31)	2.00(1.00-3.00)

How important/difficult is it for you to find a suitable job or volunteer work	2.58(±0.18)	3.00(1.00-4.00)
How important/difficult is it for you to be able to perform daily activities at your current work (paid job or volunteer work)?	2.00(±0.18)	2.00(1.00-3.00)
How important/difficult is it for you to be able to move around and to use facilities at your current work?	1.95(±0.19)	2.00(1.00-3.00)
Domain 9: Community, Social and Civic Life	1.73(±0.10)	1.69(1.00-2.30)
How important/difficult is it for you to follow the news?	1.19(±0.07)	1.00(1.00-1.00)
How important/difficult is it for you to have visitors?	1.38(±0.09)	1.00(1.00-2.00)
How important/difficult is it for you to attend social events (e.g. visit someone or a party)?	2.12(±0.15)	2.00(1.00-3.00)
How important/difficult is it for you to go out for a meal?	2.00(±0.14)	2.00(1.00-3.00)
How important/difficult is it for you to go on holiday or to make a day trip?	2.08(±0.17)	2.00(1.00-3.00)
How important/difficult is it for you to perform physical activities or to participate in sports?	2.08(±0.19)	2.00(1.00-3.00)
How important/difficult is it for you to fill your leisure/recreational time, for example by hobbies?	1.40(±0.11)	1.00(1.00-1.00)

A2.2 Descriptive statistics of the ordinal IMQ scores (Chapter 5).

	Mean (±std)	**Median (25% IQ-75% IQ))**
Walking in familiar areas	1.43(±0.12)	1.00(1.00-2.00)
Walking in unfamiliar areas	2.57(±0.22)	2.00(1.00-4.00)
Moving about in the home	1.46(±0.14)	1.00(1.00-1.25)
Moving about at work	1.23(±0.10)	1.00(1.00-1.00)
Moving about in the classroom	1.09(±0.10)	1.00(1.00-1.00)
Moving about in stores	2.17(±0.20)	2.00(1.00-3.00)
Moving about in outdoors	1.80(±0.16)	1.00(1.00-3.00)
Moving about in crowded situations	2.87(±0.24)	3.00(1.00-4.00)
Walking at night	3.37(±0.22)	4.00(2.00-5.00)
Using public transport	1.80(±0.17)	1.00(1.00-3.00)
Detecting ascending stairwells	1.93(±0.17)	1.00(1.00-3.00)
Detecting descending stairwells	2.59(±0.20)	3.00(1.00-4.00)
Walking up steps	1.72(±0.13)	1.00(1.00-2.00)
Walking down steps	2.36(±0.18)	2.00(1.00-3.25)
Stepping onto curbs	2.00(±0.16)	2.00(1.00-3.00)
Stepping off curbs	2.08(±0.16)	2.00(1.00-3.00)
Walking through doorways	1.80(±0.16)	1.00(1.00-3.00)
Walking in high-glare areas	3.20(±0.19)	4.00(2.00-4.00)
Adjusting to lighting changes during the day:		
Indoor to outdoor	2.62(±0.18)	3.00(1.00-4.00)
Outdoor to indoor	2.74(±0.18)	3.00(1.00-4.00)
Adjusting to lighting changes at night:		
Indoor to streetlights	2.96(±0.19)	3.00(2.00-4.00)
Streetlights to indoor	2.34(±0.20)	2.00(1.00-3.25)
Walking in dimly lit indoor areas	2.80(±0.17)	3.00(2.00-4.00)
Being aware of another person's presence	2.46(±0.20)	2.00(1.00-4.00)
Avoiding bumping into:		
People	2.56(±0.20)	2.00(1.00-4.00)
Walls	1.82(±0.15)	1.00(1.00-3.00)
Head-height objects	2.92(±0.19)	3.00(2.00-4.00)
Shoulder-height objects	2.26(±0.20)	2.00(1.00-3.25)
Waist-height objects	1.90(±0.17)	1.00(1.00-3.00)
Knee-height objects	2.44(±0.21)	2.00(1.00-4.00)
Low-lying objects	2.42(±0.21)	2.00(1.00-4.00)
Avoiding tripping over uneven travel surfaces	2.78(±0.18)	3.00(2.00-4.00)
Moving around in social gatherings	2.42(±0.20)	2.00(1.00-4.00)
Finding restrooms in public places	2.18(±0.22)	1.00(1.00-4.00)
Seeing cars at intersections	2.48(±0.21)	2.00(1.00-4.00)
	Mean (±std)	Median (25% IQ-75% IQ))

Walking in familiar areas	1.43(±0.12)	1.00(1.00-2.00)
Walking in unfamiliar areas	2.57(±0.22)	2.00(1.00-4.00)
Moving about in the home	1.46(±0.14)	1.00(1.00-1.25)
Moving about at work	1.23(±0.10)	1.00(1.00-1.00)
Moving about in the classroom	1.09(±0.10)	1.00(1.00-1.00)
Moving about in stores	2.17(±0.20)	2.00(1.00-3.00)
Moving about in outdoors	1.80(±0.16)	1.00(1.00-3.00)
Moving about in crowded situations	2.87(±0.24)	3.00(1.00-4.00)
Walking at night	3.37(±0.22)	4.00(2.00-5.00)
Using public transport	1.80(±0.17)	1.00(1.00-3.00)
Detecting ascending stairwells	1.93(±0.17)	1.00(1.00-3.00)
Detecting descending stairwells	2.59(±0.20)	3.00(1.00-4.00)
Walking up steps	1.72(±0.13)	1.00(1.00-2.00)
Walking down steps	2.36(±0.18)	2.00(1.00-3.25)
Stepping onto curbs	2.00(±0.16)	2.00(1.00-3.00)
Stepping off curbs	2.08(±0.16)	2.00(1.00-3.00)
Walking through doorways	1.80(±0.16)	1.00(1.00-3.00)
Walking in high-glare areas	3.20(±0.19)	4.00(2.00-4.00)
Adjusting to lighting changes during the day:		
Indoor to outdoor	2.62(±0.18)	3.00(1.00-4.00)
Outdoor to indoor	2.74(±0.18)	3.00(1.00-4.00)
Adjusting to lighting changes at night:		
Indoor to streetlights	2.96(±0.19)	3.00(2.00-4.00)
Streetlights to indoor	2.34(±0.20)	2.00(1.00-3.25)
Walking in dimly lit indoor areas	2.80(±0.17)	3.00(2.00-4.00)
Being aware of another person's presence	2.46(±0.20)	2.00(1.00-4.00)
Avoiding bumping into:		
People	2.56(±0.20)	2.00(1.00-4.00)
Walls	1.82(±0.15)	1.00(1.00-3.00)
Head-height objects	2.92(±0.19)	3.00(2.00-4.00)
Shoulder-height objects	2.26(±0.20)	2.00(1.00-3.25)
Waist-height objects	1.90(±0.17)	1.00(1.00-3.00)
Knee-height objects	2.44(±0.21)	2.00(1.00-4.00)
Low-lying objects	2.42(±0.21)	2.00(1.00-4.00)
Avoiding tripping over uneven travel surfaces	2.78(±0.18)	3.00(2.00-4.00)
Moving around in social gatherings	2.42(±0.20)	2.00(1.00-4.00)
Finding restrooms in public places	2.18(±0.22)	1.00(1.00-4.00)
Seeing cars at intersections	2.48(±0.21)	2.00(1.00-4.00)

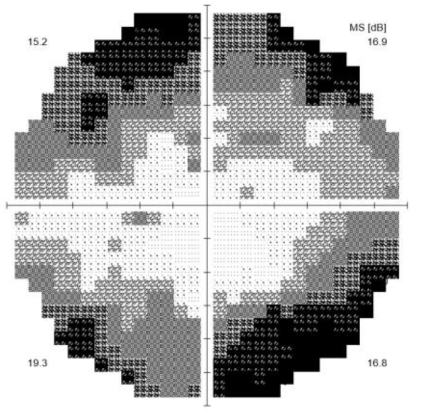
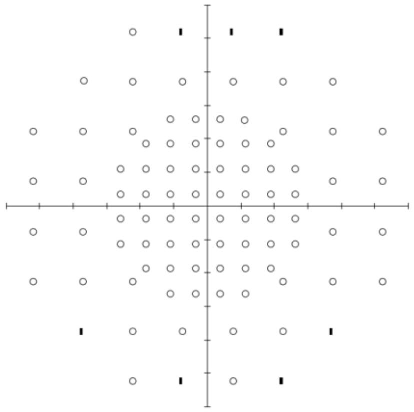
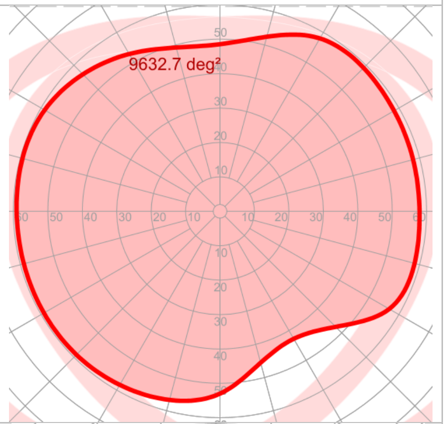
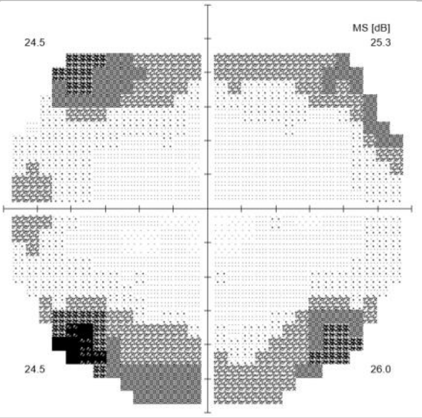
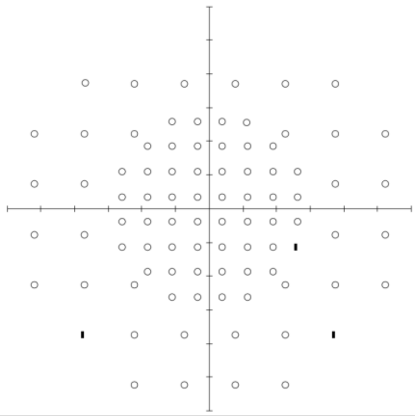
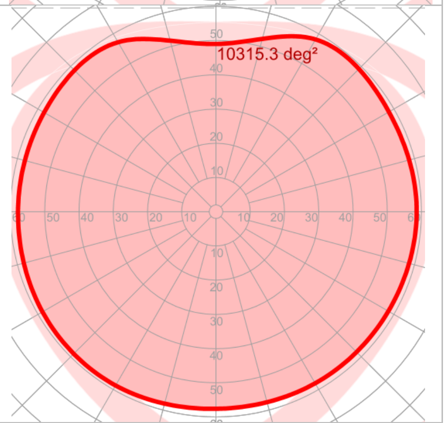
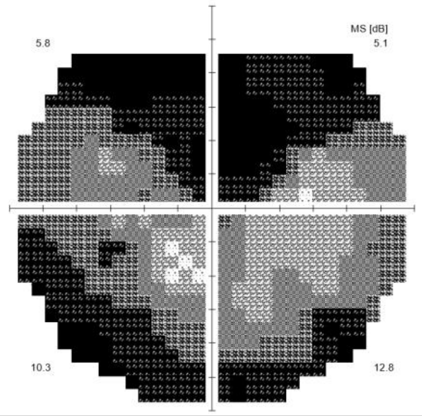
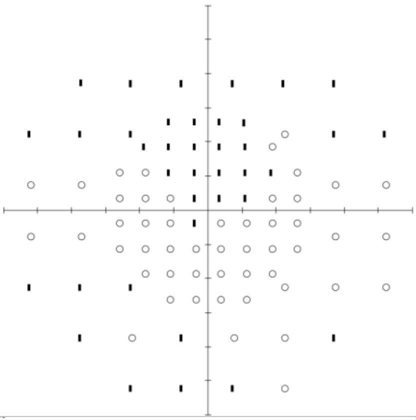
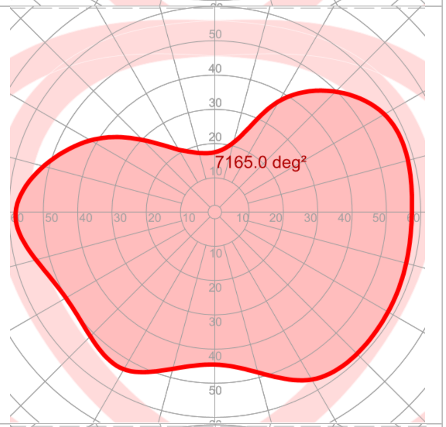
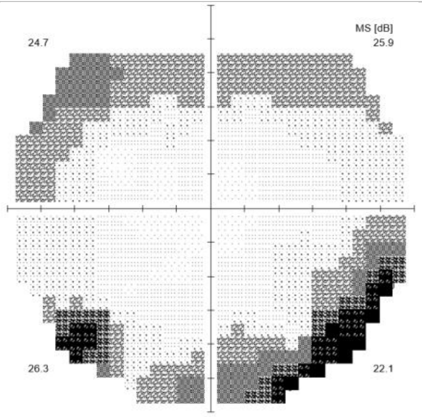
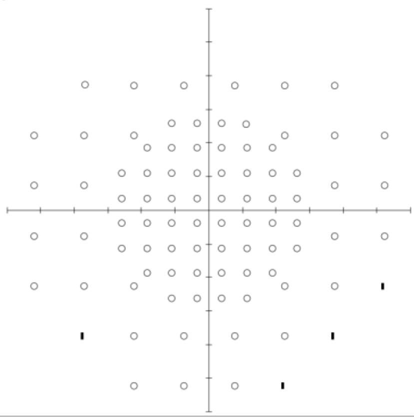
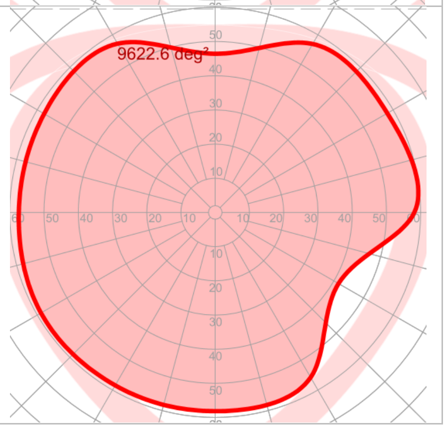
A2.3 Item parameters of the D-AI as determined by Rasch analysis (Chapter 5)

Goal	Domain	Item difficulty	SE	Infit mnsq	Oufit mnsq	Applic-ability
Mending clothes	Domestic Life	-1.60	0.21	2	1.78	34
Doing general maintenance tasks at home	Domestic life	-1.38	0.2	0.93	0.87	40
Reading	Learning and Applying Knowledge	-1.09	0.18	0.93	0.93	50
Mobility indoors	Mobility	-1.06	0.18	1.18	1.52	50
Mobility outdoors	Mobility	-0.96	0.18	0.99	1.12	50
Physical activity and / or sport	Community, Social and Civic Life	-0.91	0.21	1.22	1.66	40
Applying for a job	Major Life areas	-0.86	0.3	2	1.48	17
Social events	Community, Social and Civic Life	-0.76	0.19	0.65	0.62	49
Using public transport	Mobility	-0.70	0.19	0.55	0.48	49
Holidays and trips	Community, Social and Civic Life	-0.57	0.19	0.73	0.57	50
Shopping	Domestic life	-0.50	0.19	0.49	0.4	50
Dining out	Community, Social and Civic Life	-0.45	0.19	0.89	0.81	49
Interaction with strangers	Community, Social and Civic Life	-0.39	0.19	0.87	0.63	50
Withdrawing money and paying	Domestic life	-0.37	0.2	1.24	1.58	49
Health care for another adult	Domestic life	-0.36	0.51	0.67	0.65	8
Watching TV	Learning and Applying Knowledge	-0.35	0.2	1.11	1.24	50
Personal administration	General Tasks and Demands	-0.35	0.2	1.26	0.97	50
Participating in Education	Major Life areas	-0.31	0.32	1.09	1.13	14
Grocery shopping	Domestic life	-0.24	0.2	0.58	0.6	50

Writing	Learning and Applying Knowledge	-0.16	0.2	0.97	0.71	50
Accessibility at work, such as moving around and using facilities	Major Life areas	-0.12	0.28	1.15	1.61	29
Working activities	Major Life areas	-0.08	0.26	1.27	1.17	33
Cleaning and tidying up	Domestic life	-0.07	0.2	1	0.91	50
Using a computer	Communicatio n	-0.07	0.21	1.25	2.34	46
Relationship with loved ones	Interpersonal Interactions and Relationships	0.01	0.21	1.26	2.69	50
Interaction with colleagues	Interpersonal Interactions and Relationships	0.09	0.28	0.81	0.53	31
Dealing with personal correspondence	Communicatio n	0.10	0.21	1.4	0.98	50
Mobility at home	Mobility	0.14	0.21	1.21	1.71	50
Managing finances	Major Life areas	0.14	0.21	1.84	1.31	50
Getting information	Major Life areas	0.23	0.21	0.82	0.53	49
Communicating with people face to face	Interpersonal Interactions and Relationships	0.28	0.22	1.25	1	50
Having visitors	Community, Social and Civic Life	0.46	0.23	0.77	0.58	49
Prepare your usual daily meals	Domestic life	0.46	0.23	0.92	0.66	48
Recreational / leisure time activities	Community, Social and Civic Life	0.52	0.23	1.79	1.79	50
Following a schedule and getting to appointments on time	General Tasks and Demands	0.52	0.23	1.18	0.7	50
Pet care	Domestic life	0.55	0.36	0.34	0.41	14
(Grand) child care	Domestic life	0.81	0.44	0.62	0.33	16
Doing laundry	Domestic life	0.83	0.25	1	0.54	46
Using a telephone	Communicatio n	1.00	0.26	0.94	0.45	50
Personal health care and medication	Self-care	1.14	0.27	0.97	0.43	50

Following the news	Community, Social and Civic Life	1.38	0.3	0.89	0.37	50
Dressing	Self-care	1.38	0.3	0.94	0.66	50
Eating and drinking	Self-care	1.78	0.35	0.53	0.27	50
Personal hygiene	Self-care	1.91	0.36	0.6	1.98	50

A2.4 Visual field plots (Chapter 5)

	Binocular grey scale	Binocular suprathreshold	Binocular kinetic
01			
02			
03			
04			

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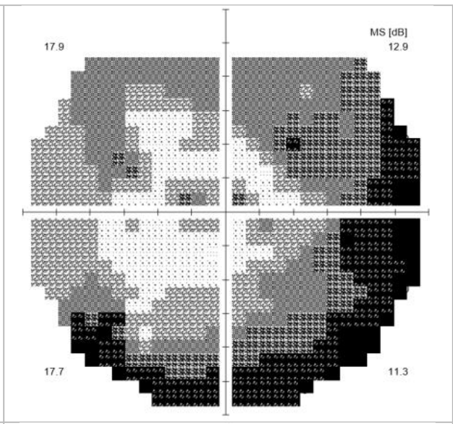
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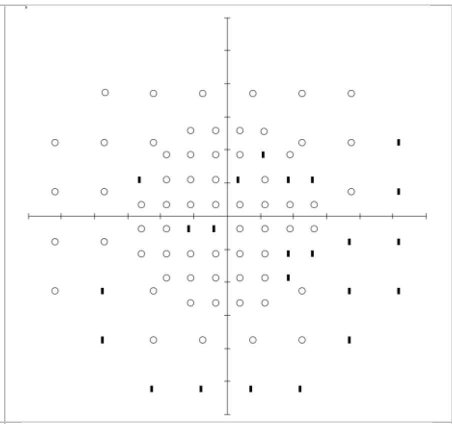
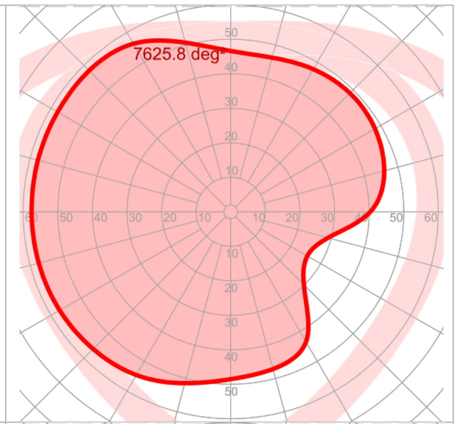
17.7
11.3

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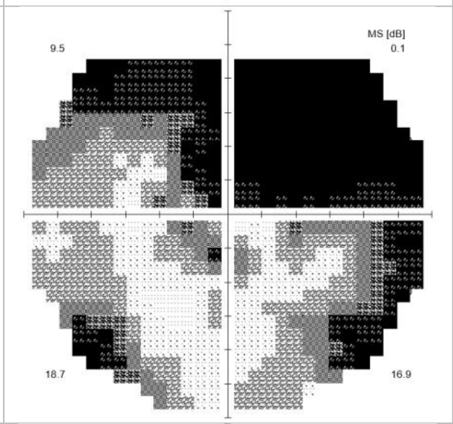
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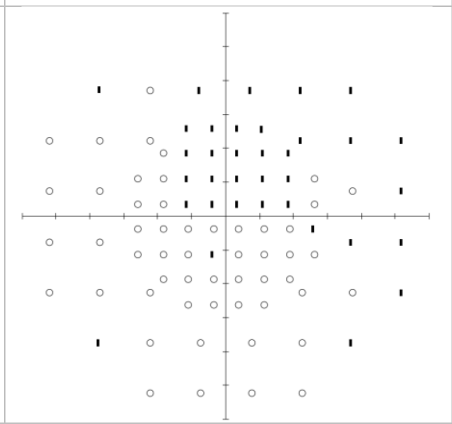

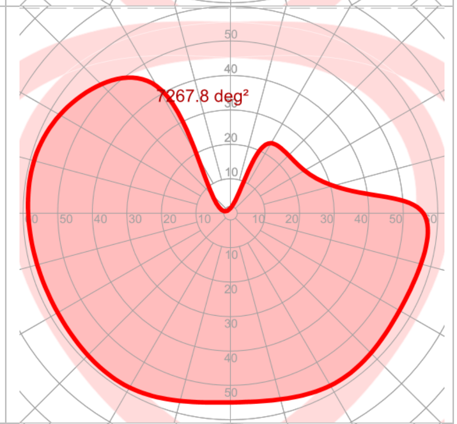
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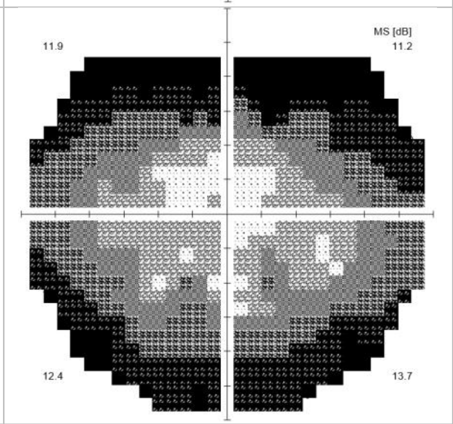
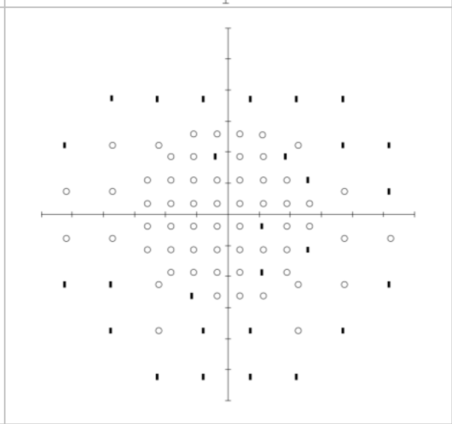
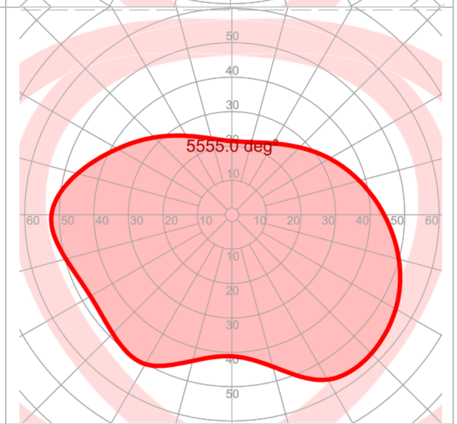
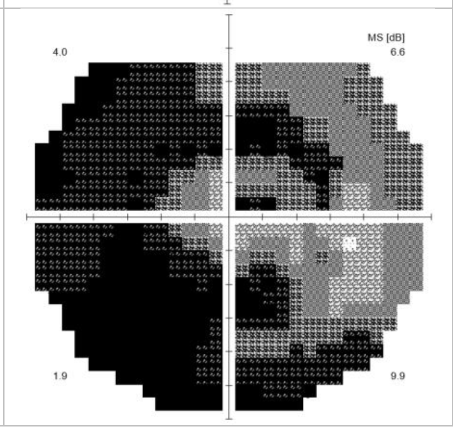
07


MS [dB]
11.9
11.2
12.4
13.7




5555.0 deg²

08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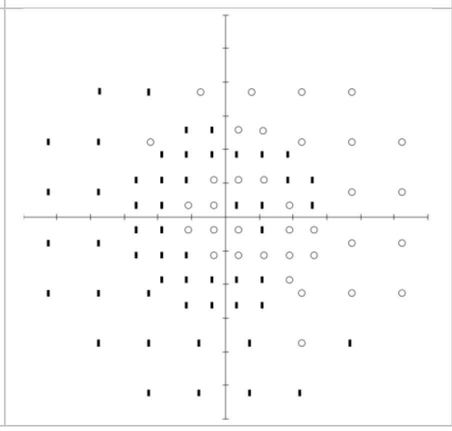
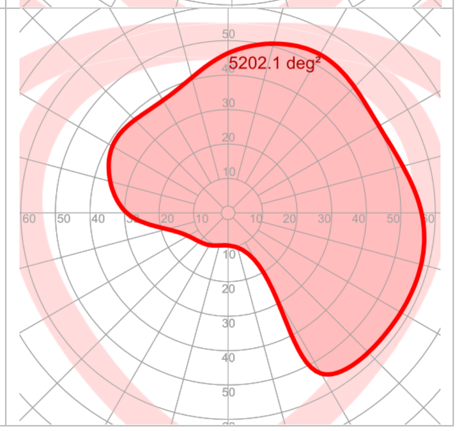
9.9

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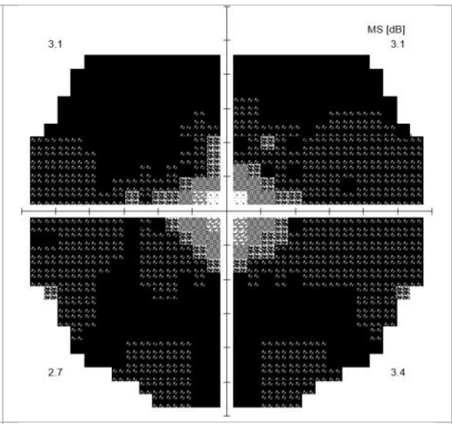
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3.1
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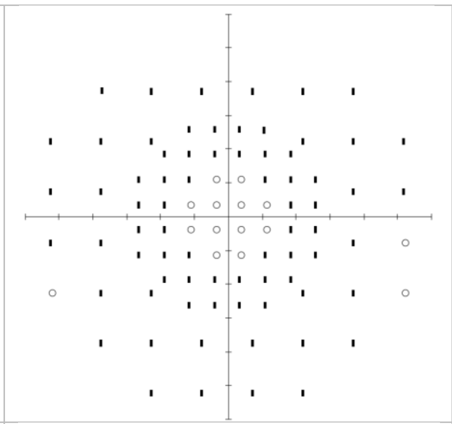
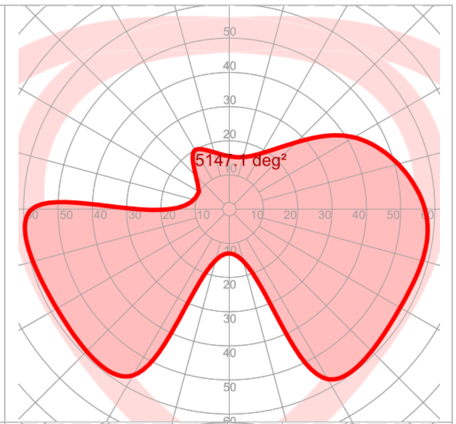
3.4

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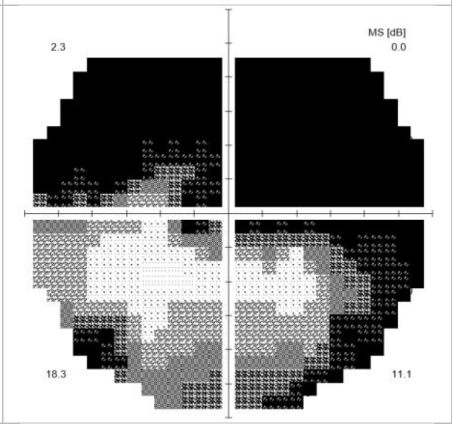
10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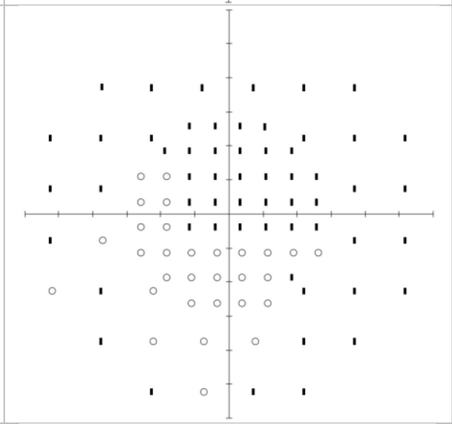
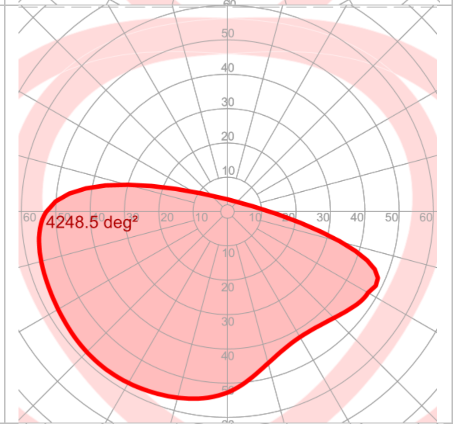
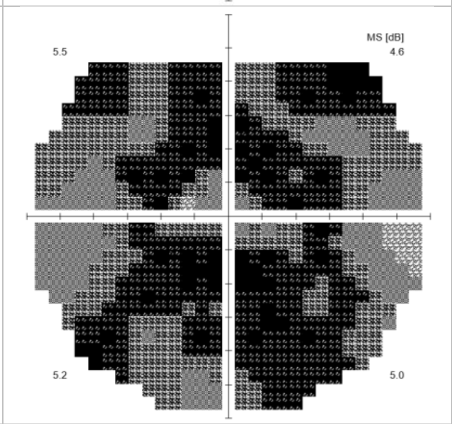
11.1




4248.5 deg²

11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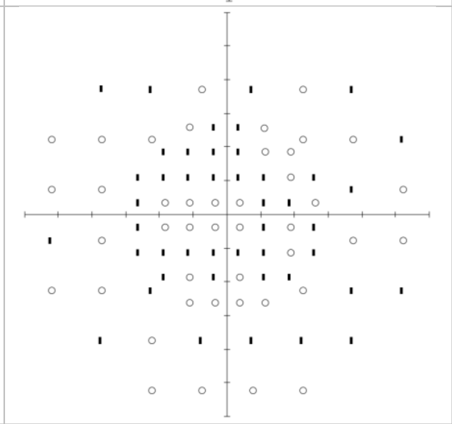
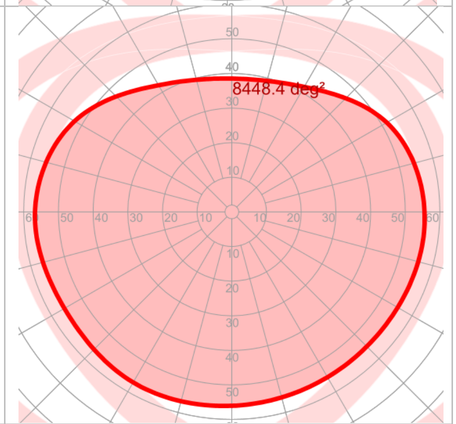
4.6
5.2
5.0

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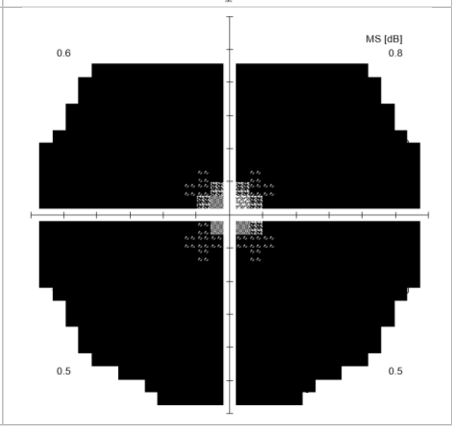
12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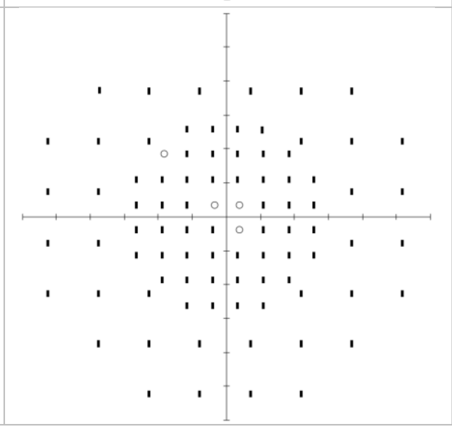
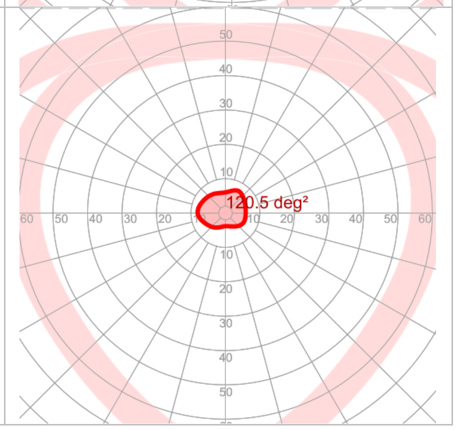
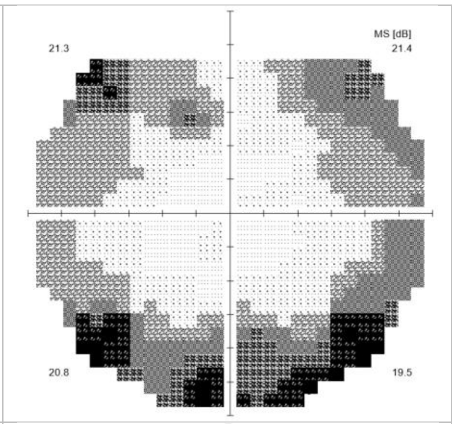
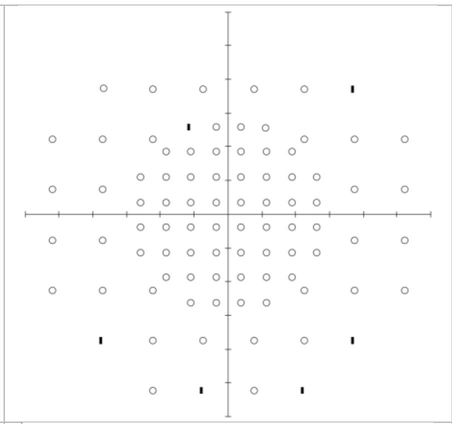
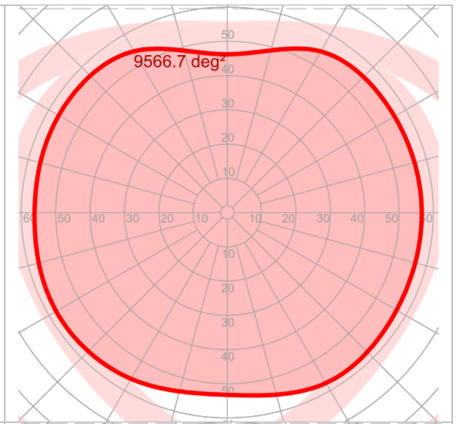
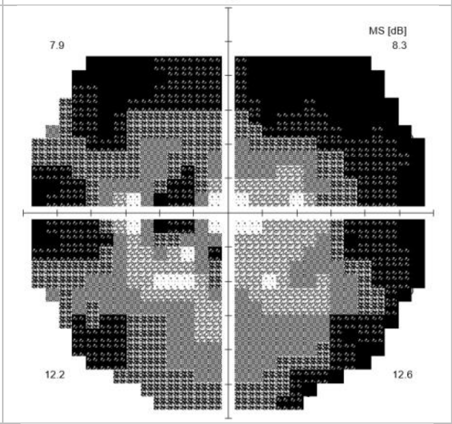
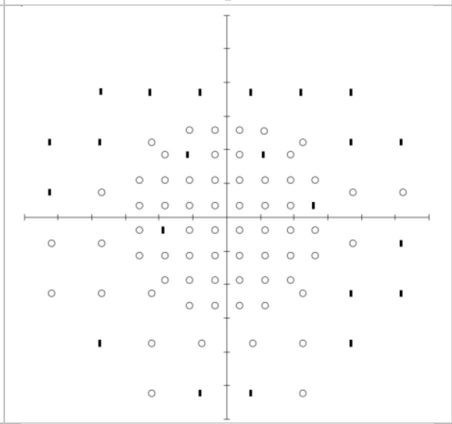
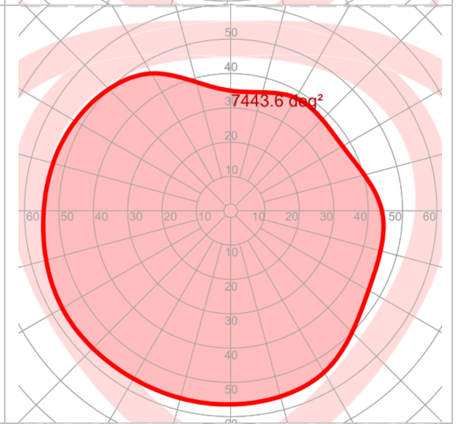
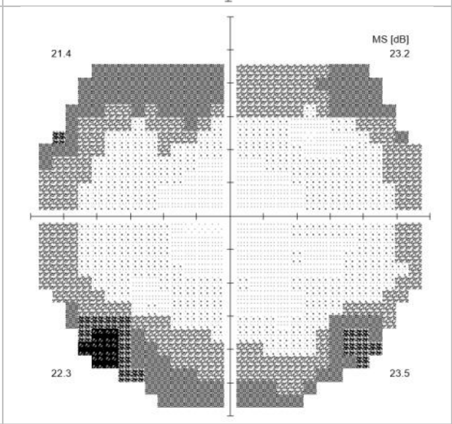
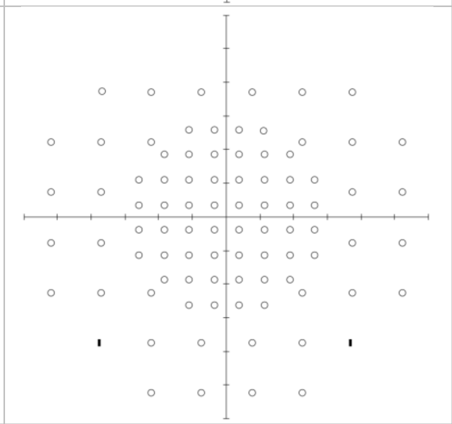
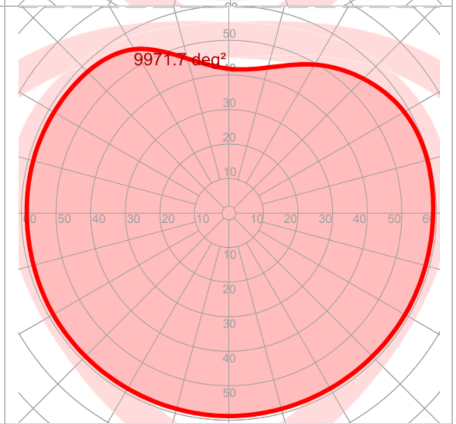
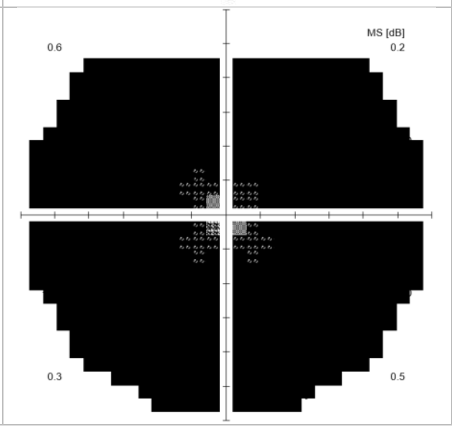
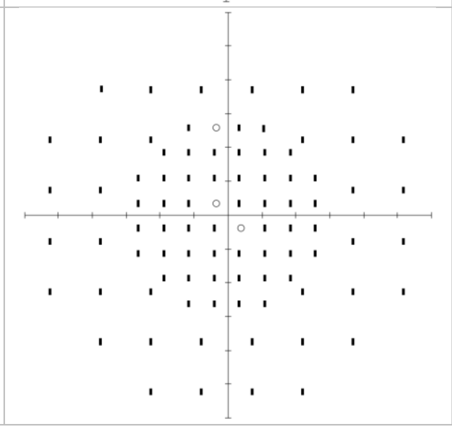
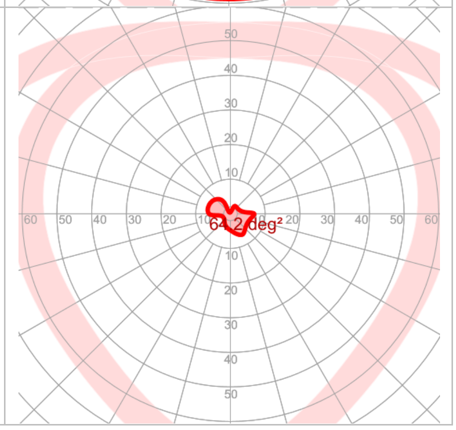
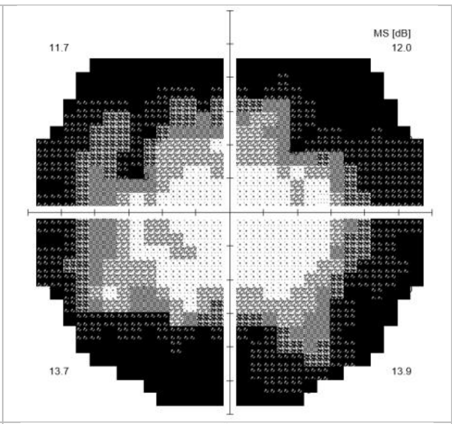
0.5
0.5

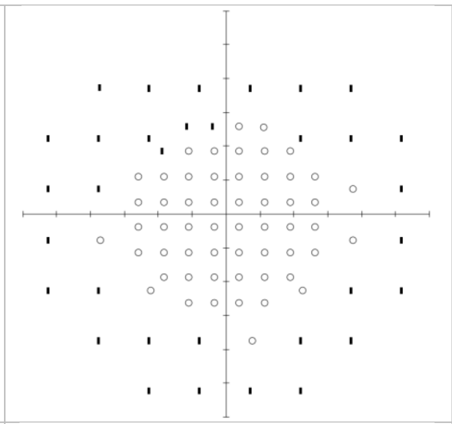


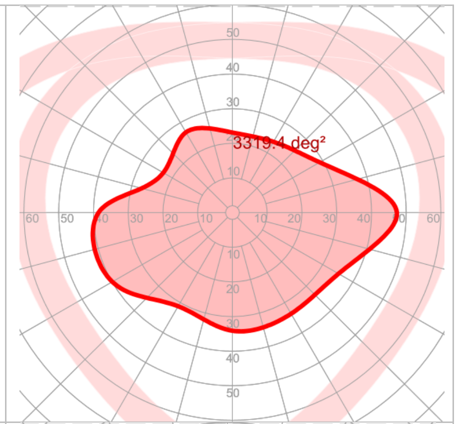

120.5 deg²

13	 MS [dB] 21.3 21.4 20.8 19.5		 9566.7 deg^2
15	 MS [dB] 7.9 8.3 12.2 12.6		 7443.6 deg^2
16	 MS [dB] 21.4 23.2 22.3 23.5		 9971.7 deg^2
18	 MS [dB] 0.6 0.2 0.3 0.5		 64.2 deg^2

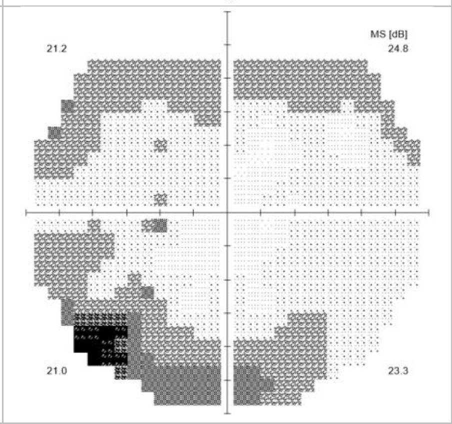
19

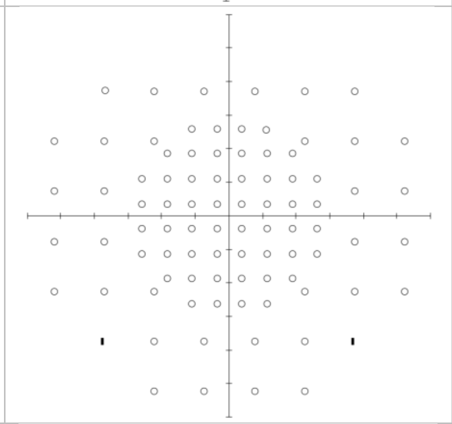

MS [dB]
11.7
12.0
13.7
13.9

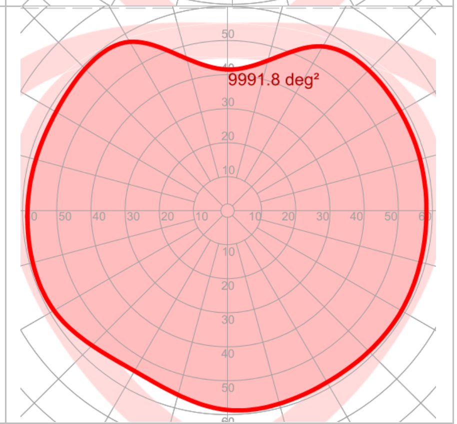



3319.4 deg²

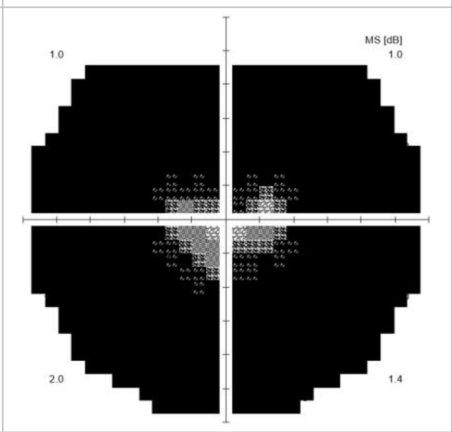
20

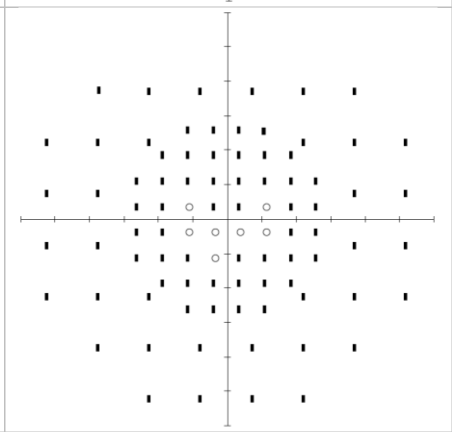

MS [dB]
21.2
24.8
21.0
23.3

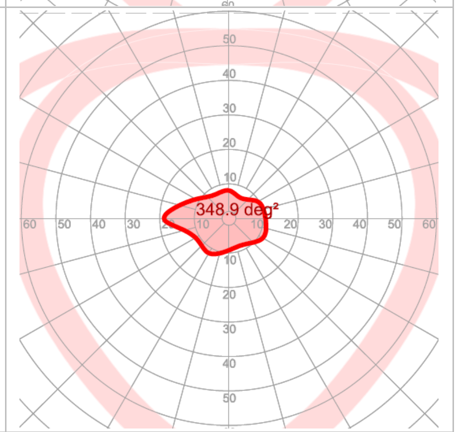



9991.8 deg²

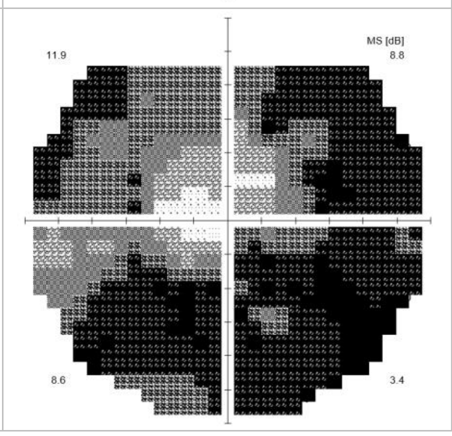
21

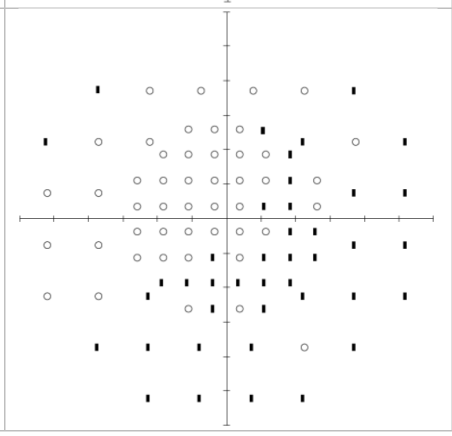

MS [dB]
1.0
1.0
2.0
1.4

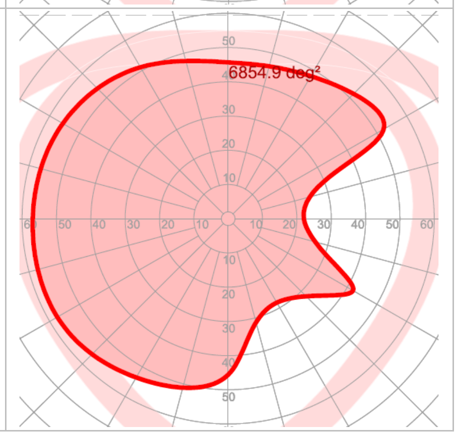



348.9 deg²

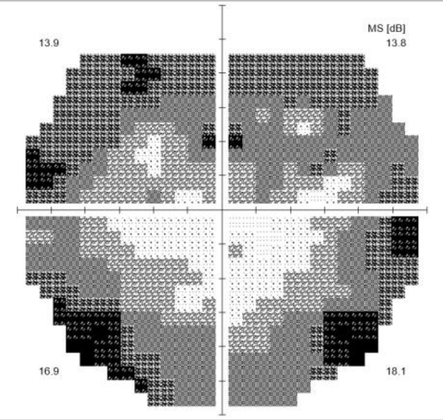
22

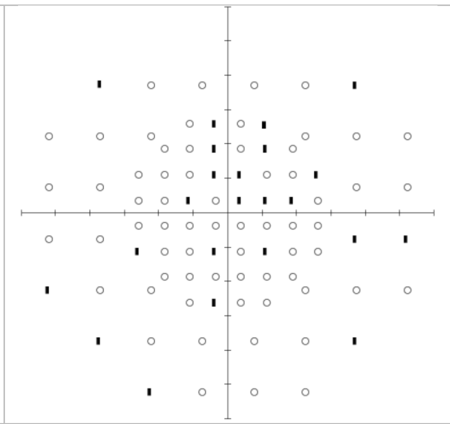

MS [dB]
11.9
8.8
8.6
3.4

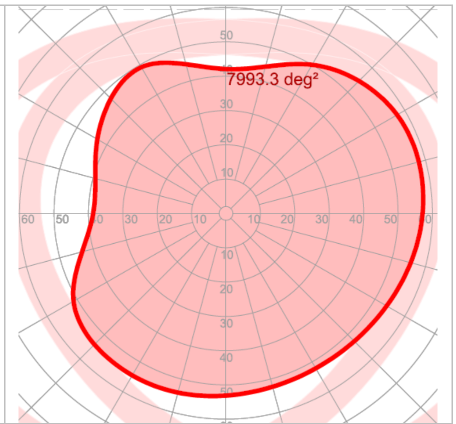



6854.9 deg²

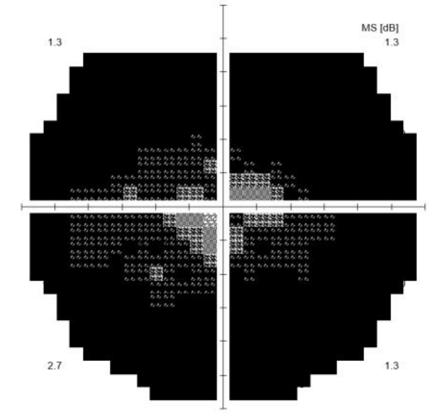
23

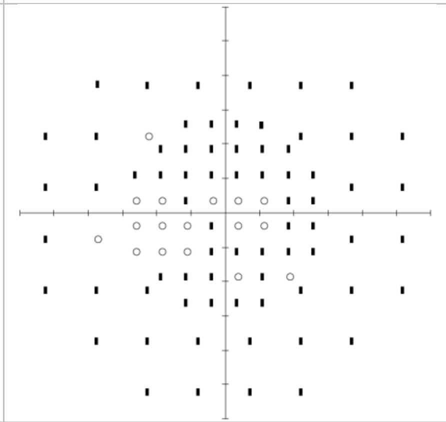

MS [dB]
13.9
13.8
16.9
18.1

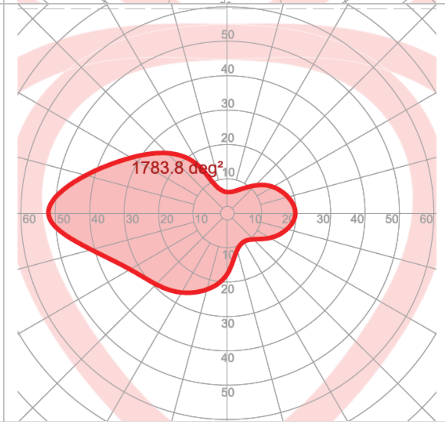



7993.3 deg²

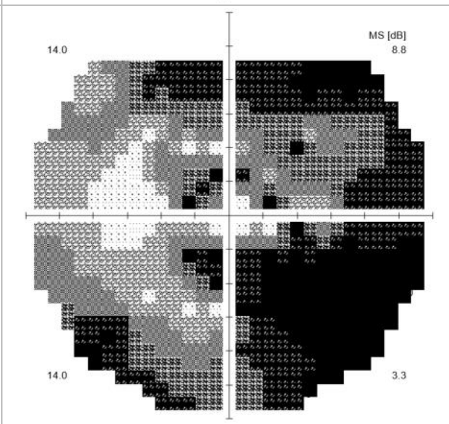
25

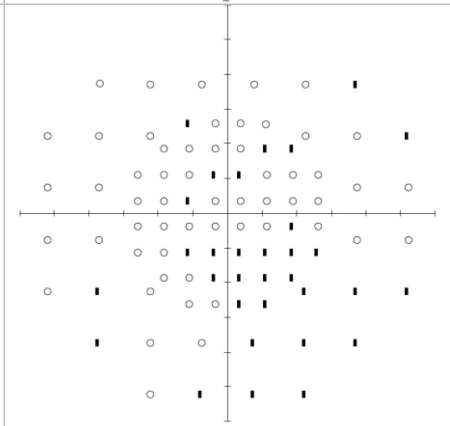

MS [dB]
1.3
1.3
2.7
1.3

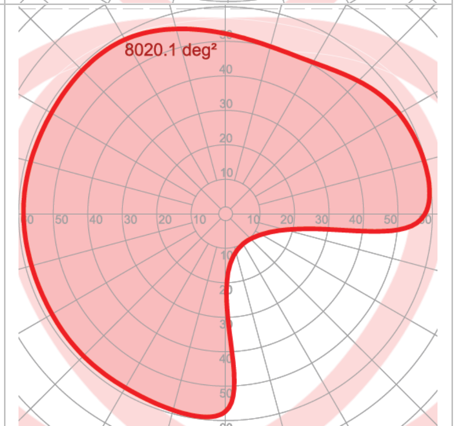



1783.8 deg²

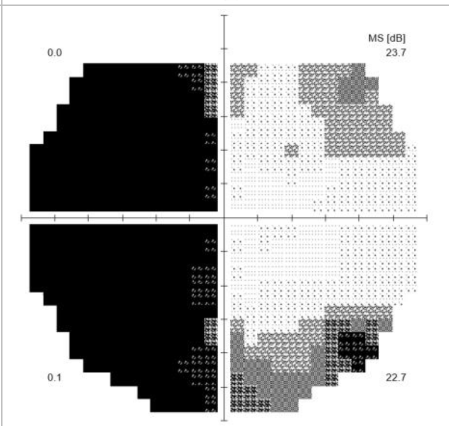
26

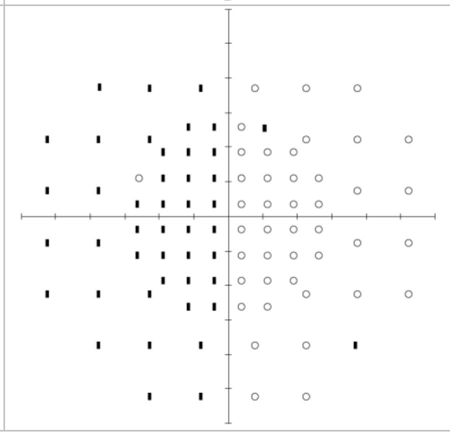

MS [dB]
14.0
8.8
14.0
3.3

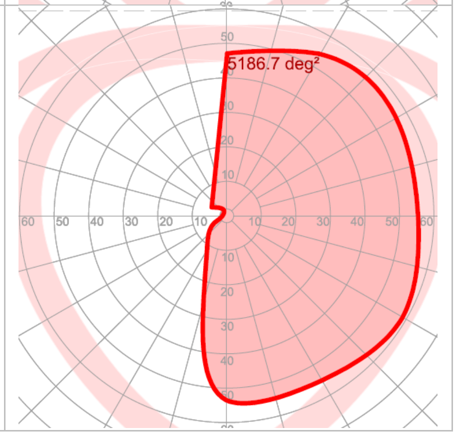


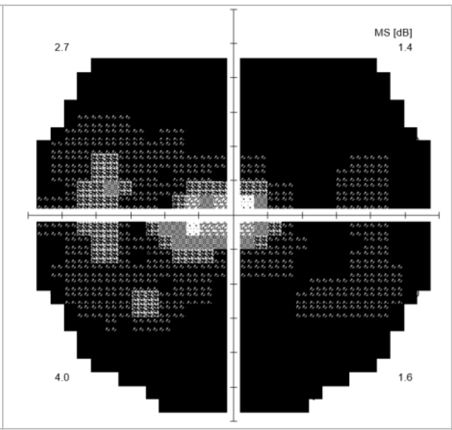
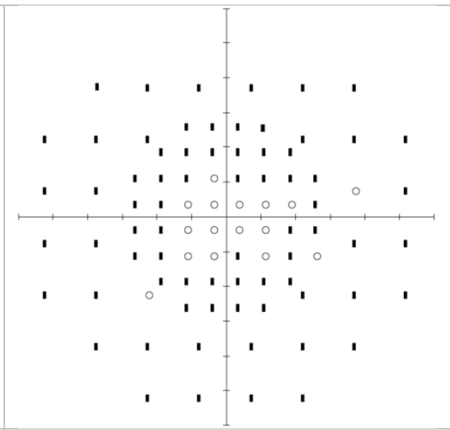
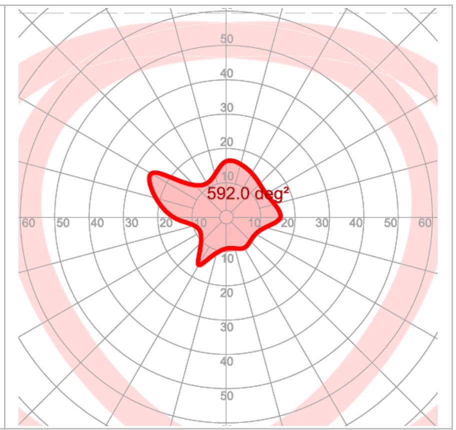
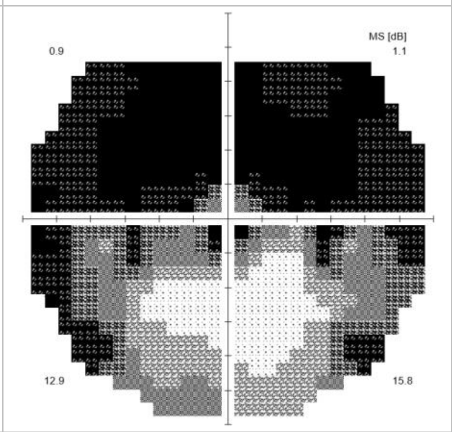
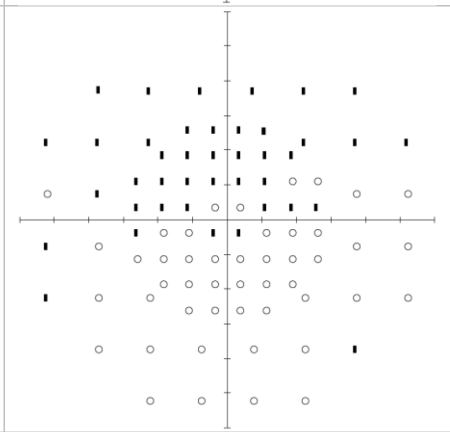
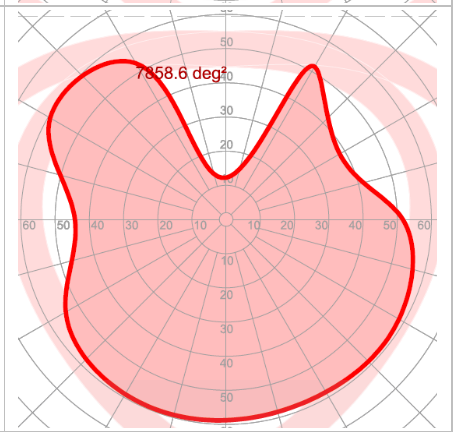
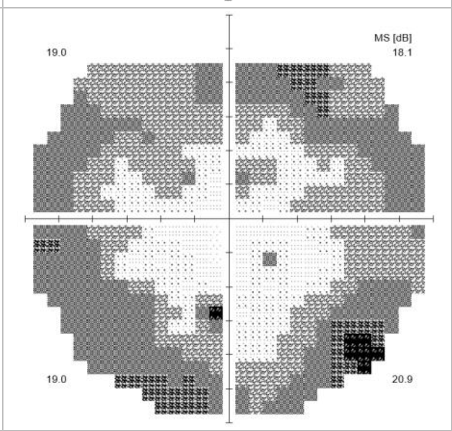
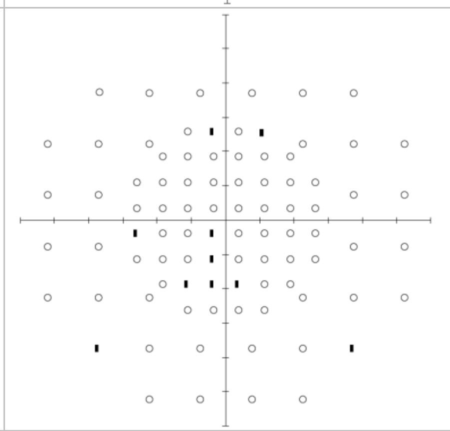
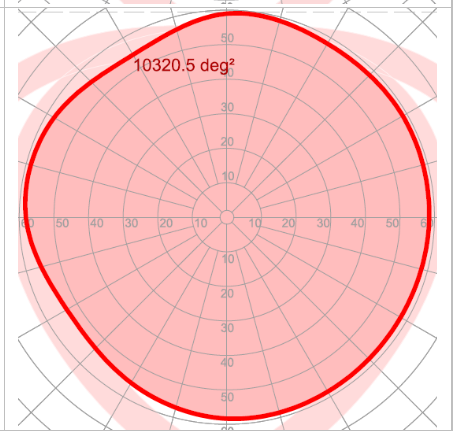
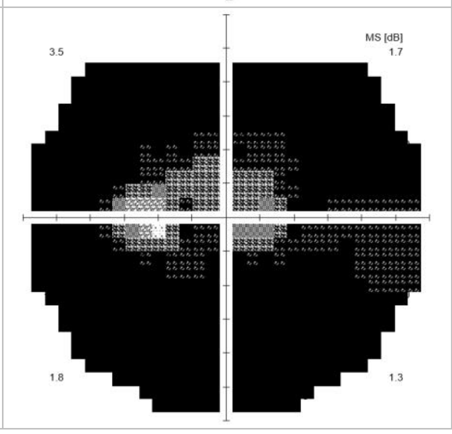
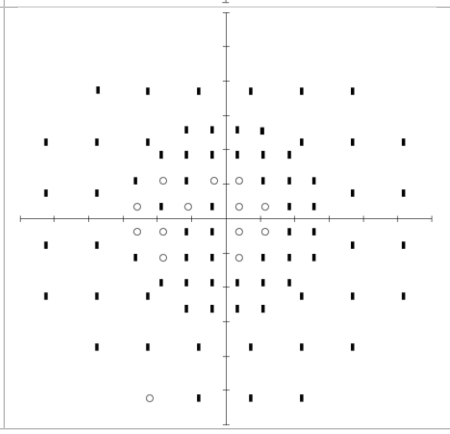
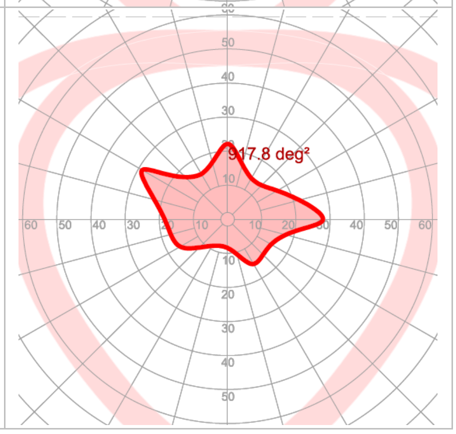

8020.1 deg²

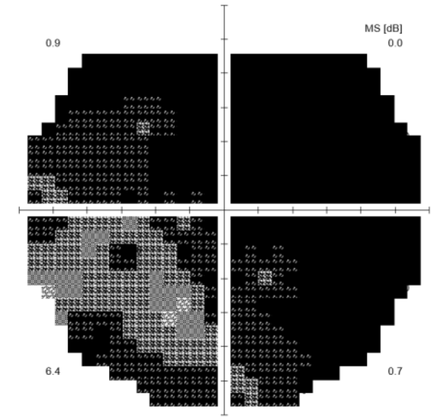
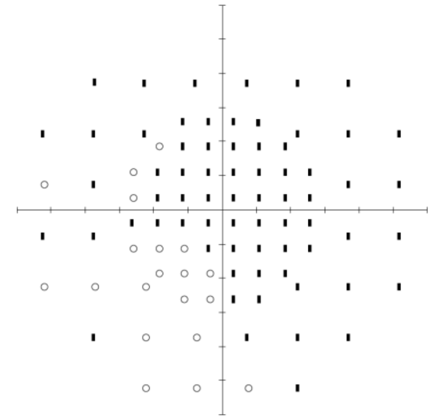
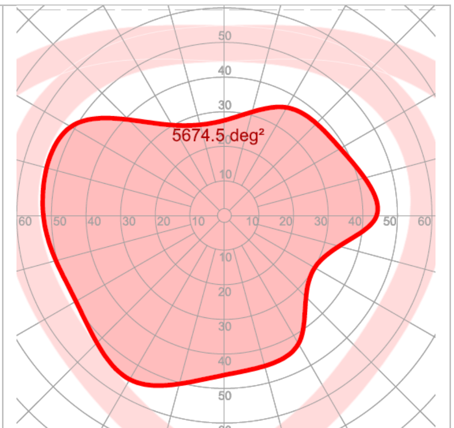
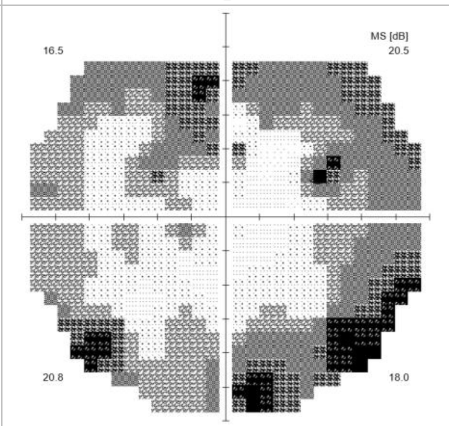
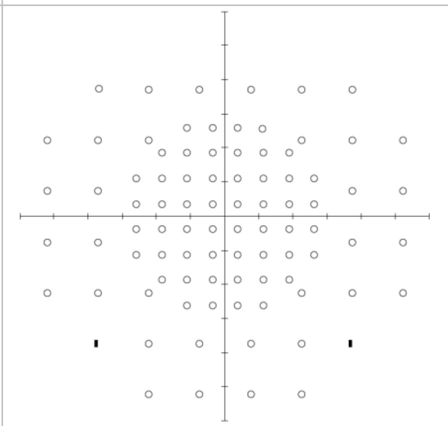
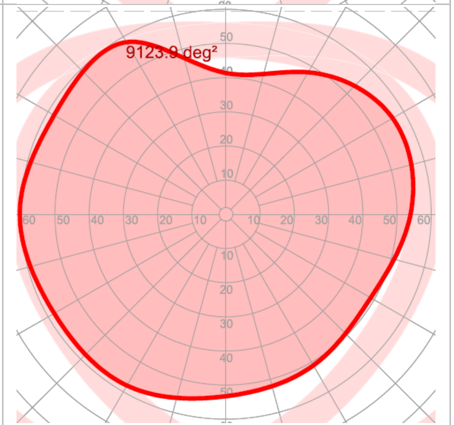
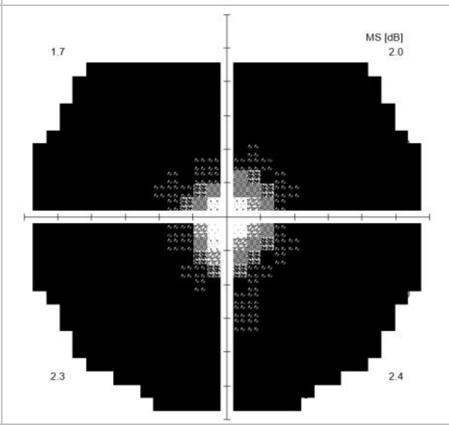
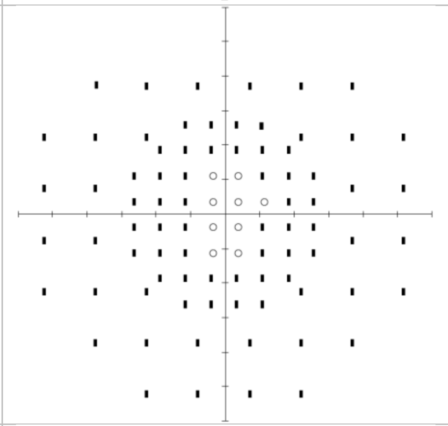
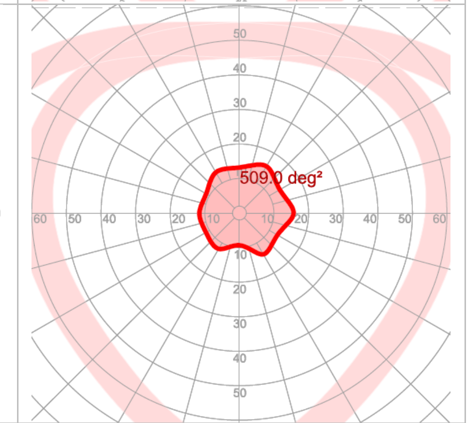
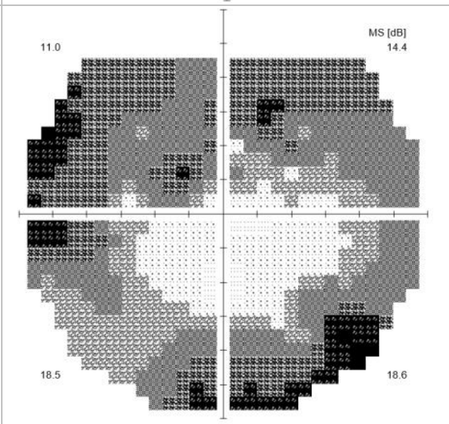
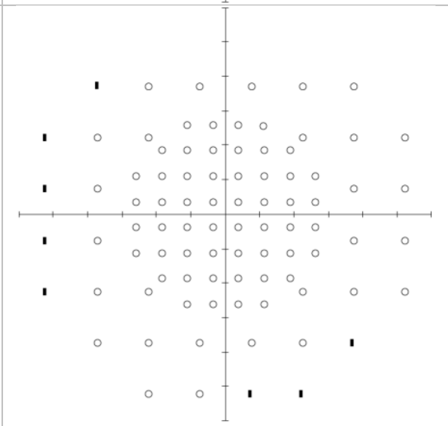
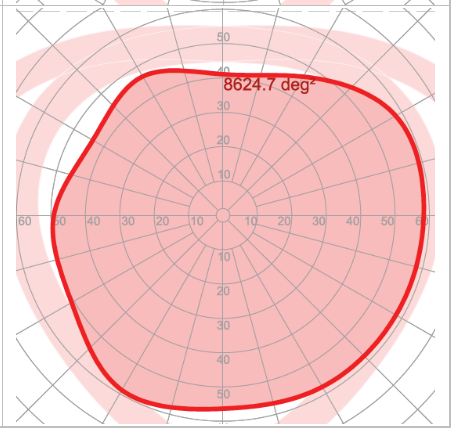
27

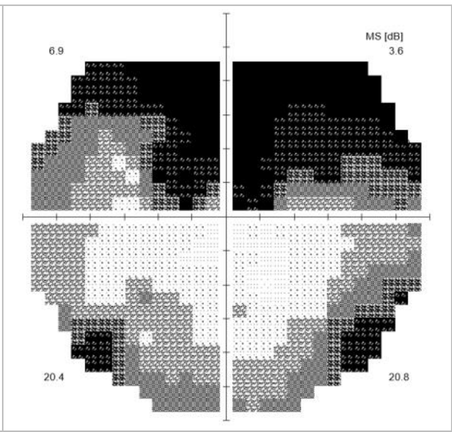
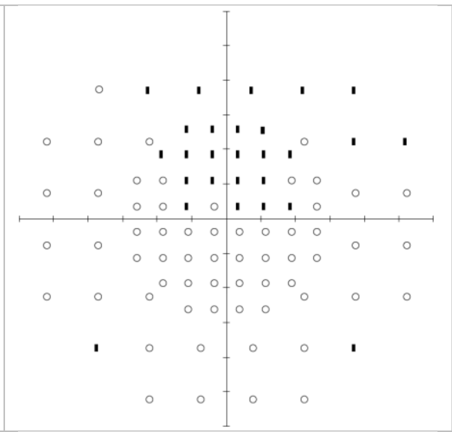
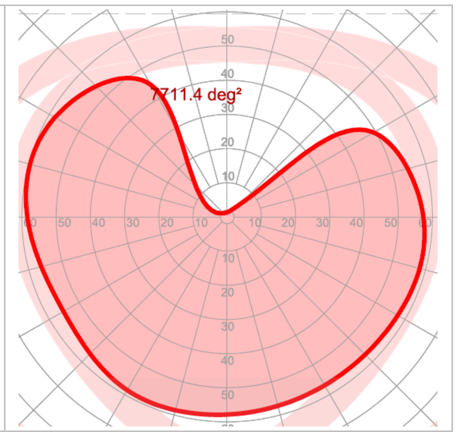
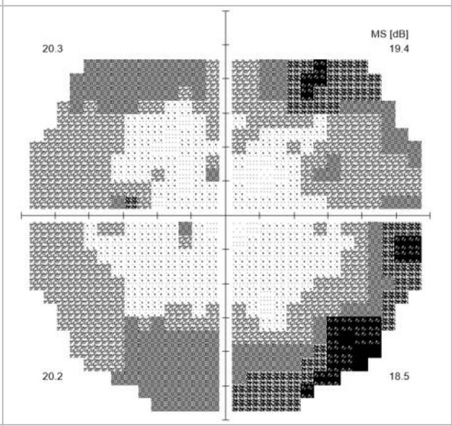
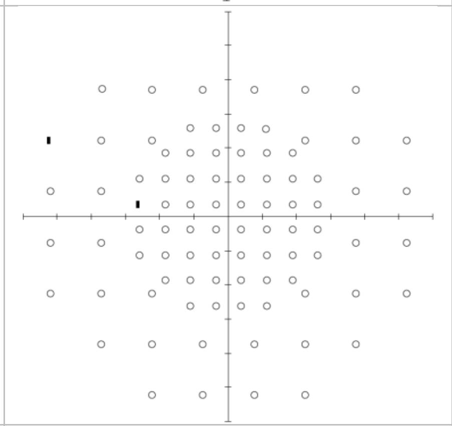
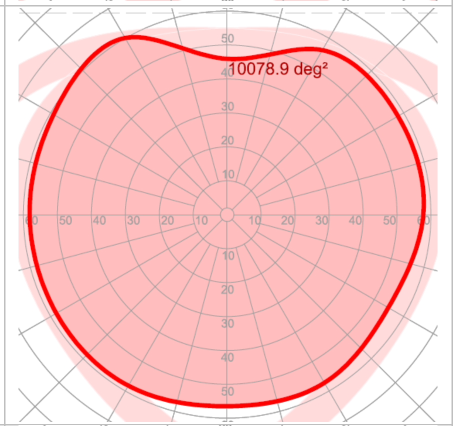
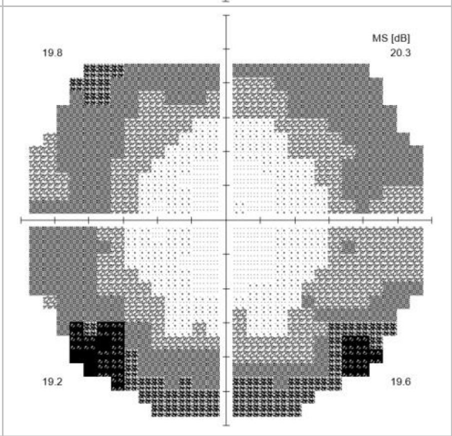
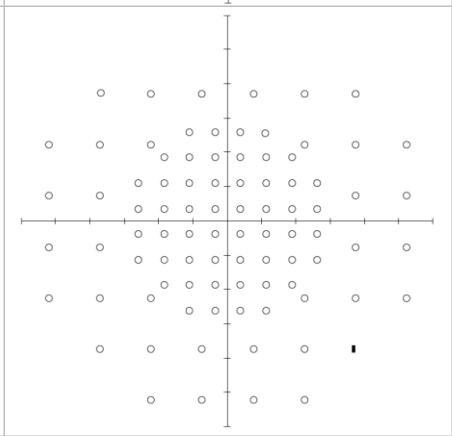
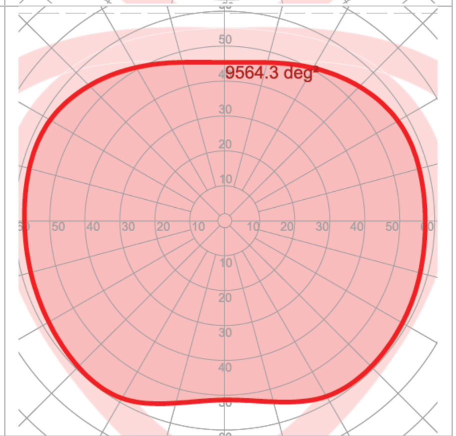
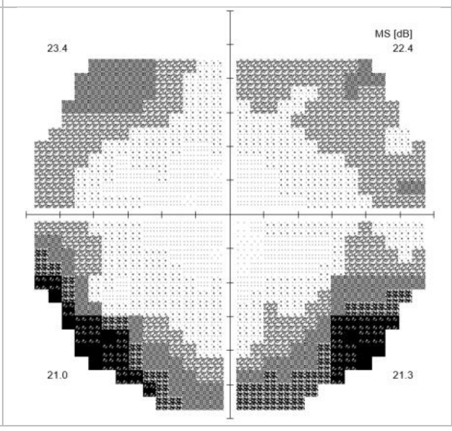
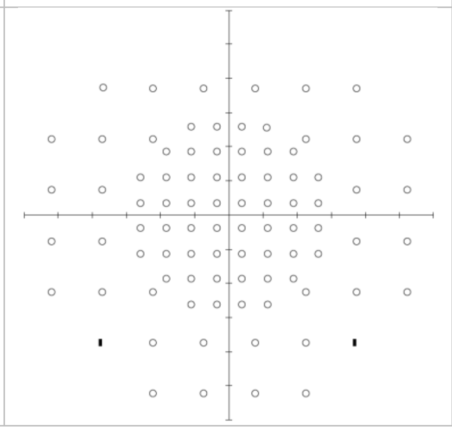
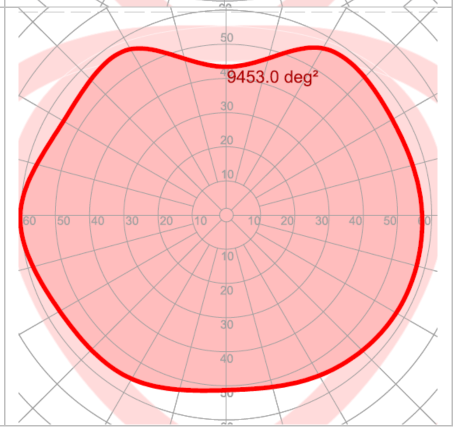

MS [dB]
0.0
23.7
0.1
22.7



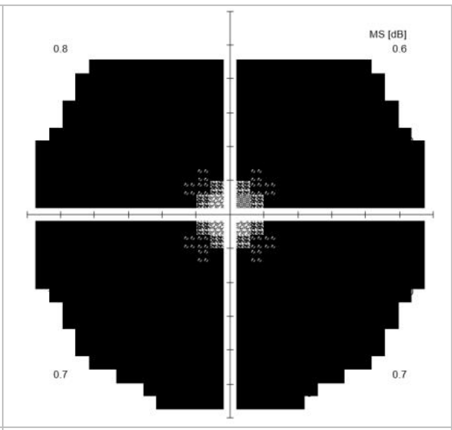

5186.7 deg²

28	MS [dB] 2.7 1.4 4.0 1.6		592.0 deg²
29	MS [dB] 0.9 1.1 12.9 15.8		7858.6 deg²
30	MS [dB] 19.0 18.1 19.0 20.9		10320.5 deg²
31	MS [dB] 3.5 1.7 1.8 1.3		917.8 deg²

32	MS [dB] 0.9 0.0 6.4 0.7		5674.5 deg²
33	MS [dB] 16.5 20.5 20.8 18.0		9123.9 deg²
34	MS [dB] 1.7 2.0 2.3 2.4		509.0 deg²
35	MS [dB] 11.0 14.4 18.5 18.6		8624.7 deg²

36	MS [dB] 6.9 3.6 20.4 20.8		7711.4 deg²
37	MS [dB] 20.3 19.4 20.2 18.5		10078.9 deg²
38	MS [dB] 19.8 20.3 19.2 19.6		9564.3 deg²
39	MS [dB] 23.4 22.4 21.0 21.3		9453.0 deg²

40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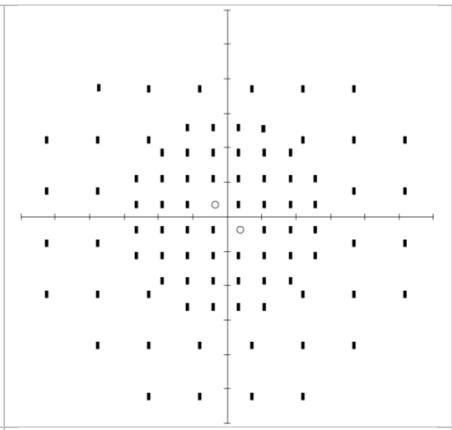
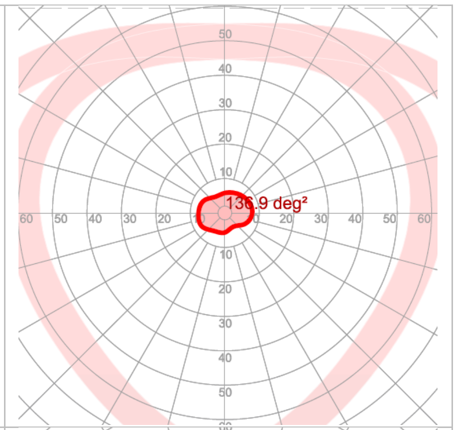
0.7
0.7





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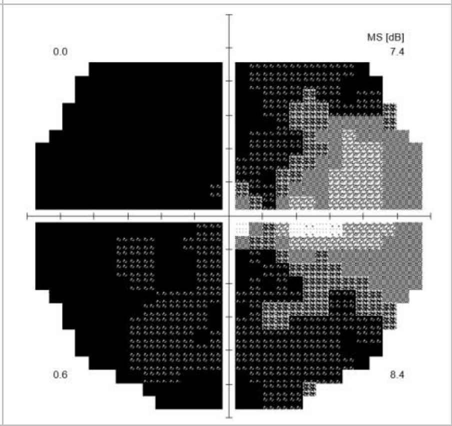
MS [dB]
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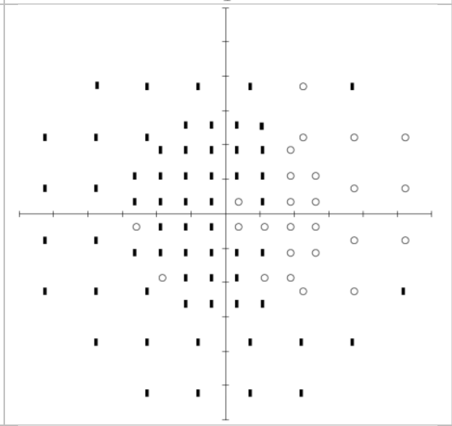
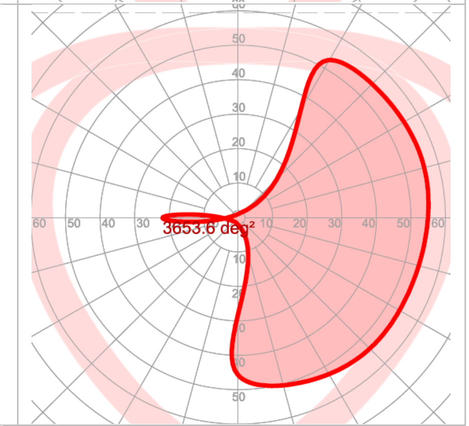
7.4
0.6
8.4




3653.6 deg²

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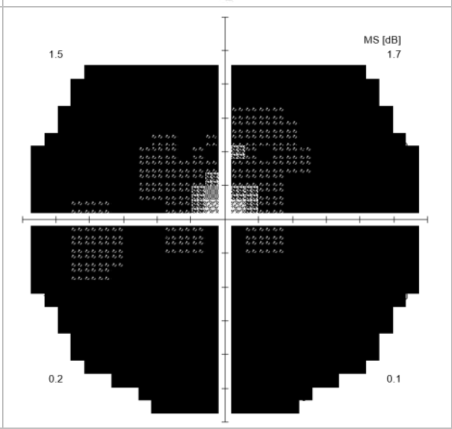
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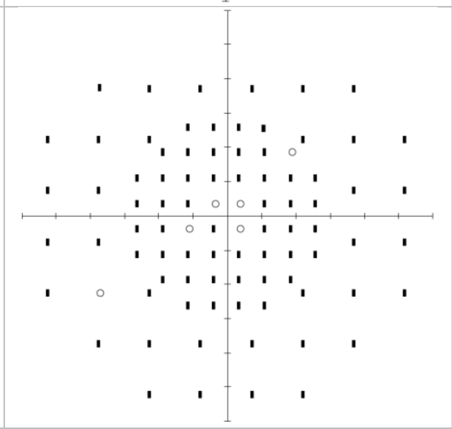
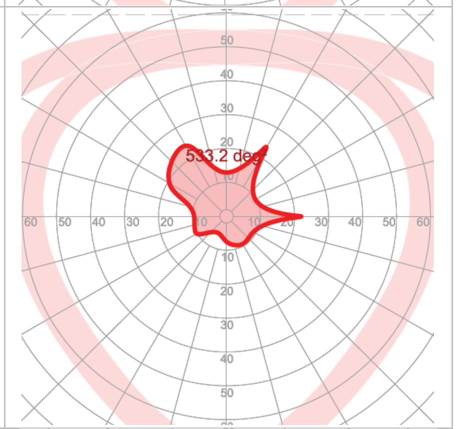
0.1




533.2 deg²

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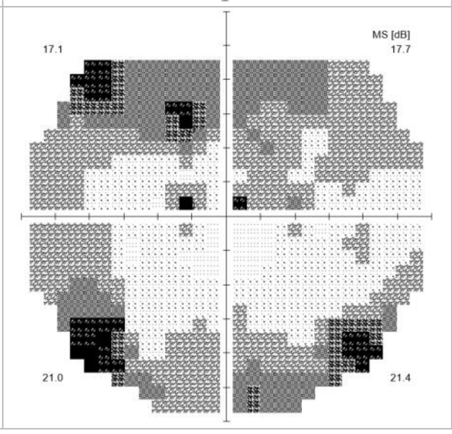
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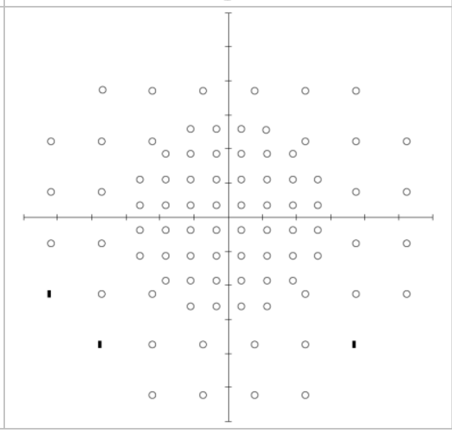
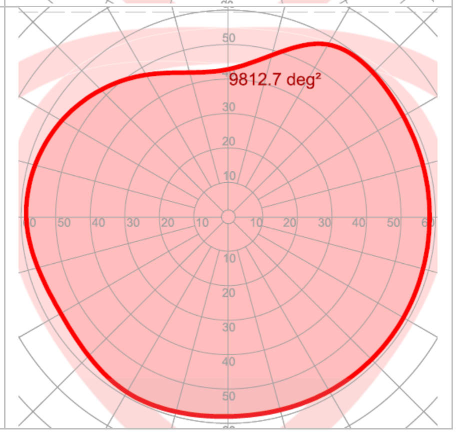
17.7
21.0
21.4

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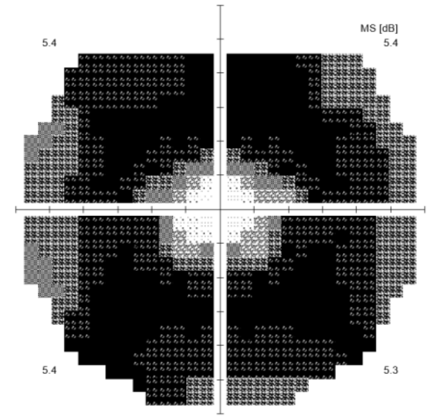
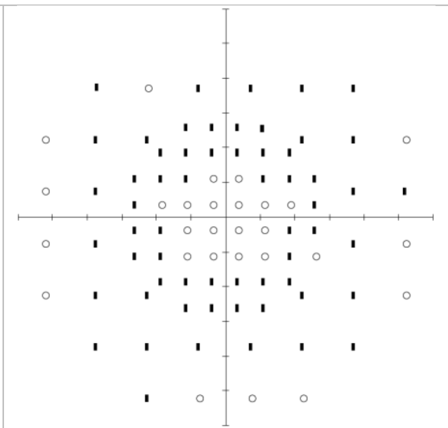
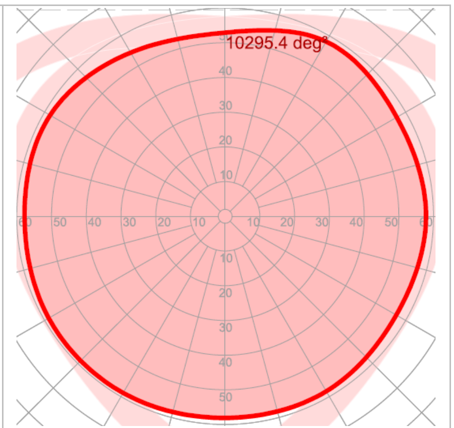
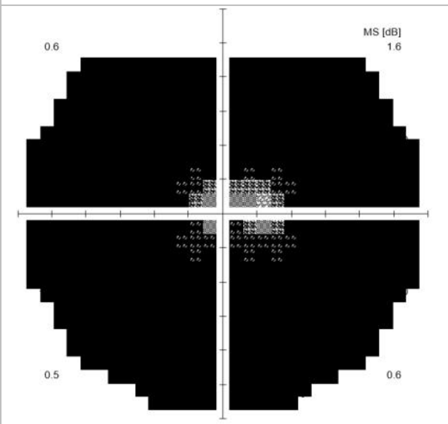
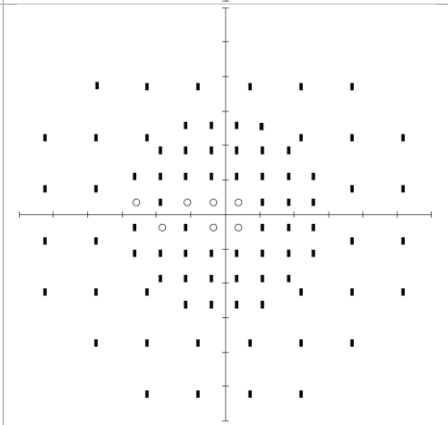
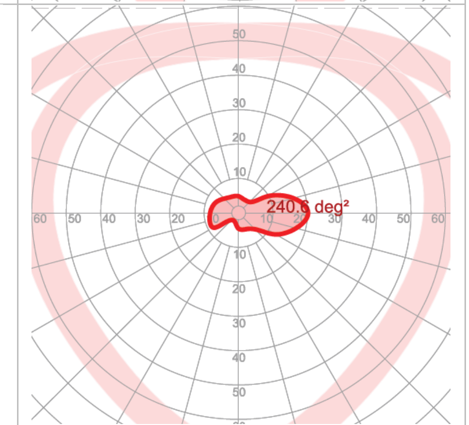
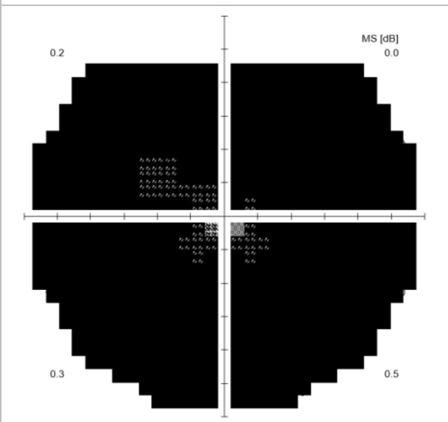
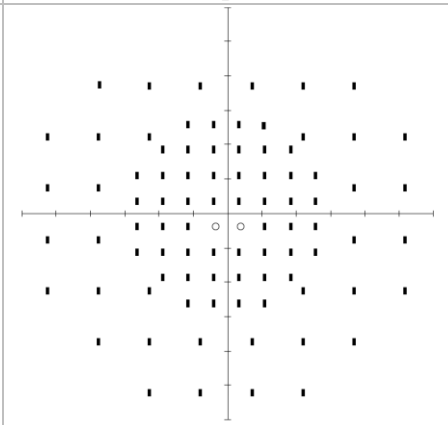
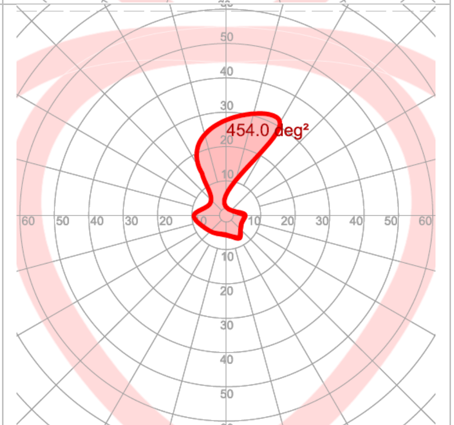
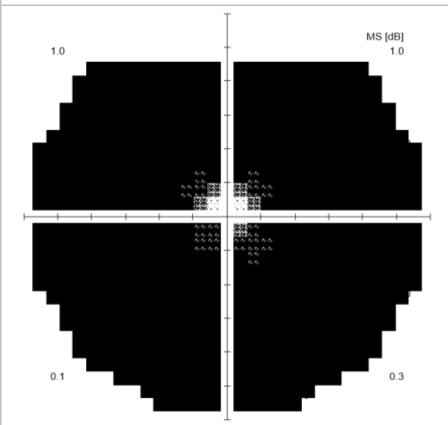
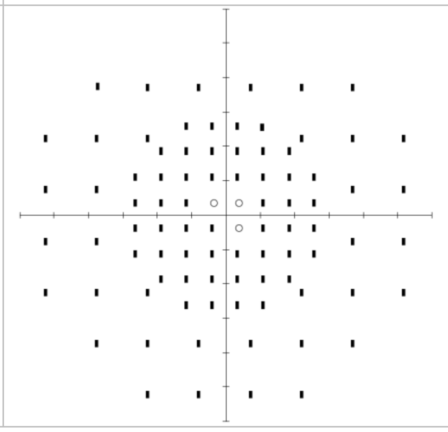
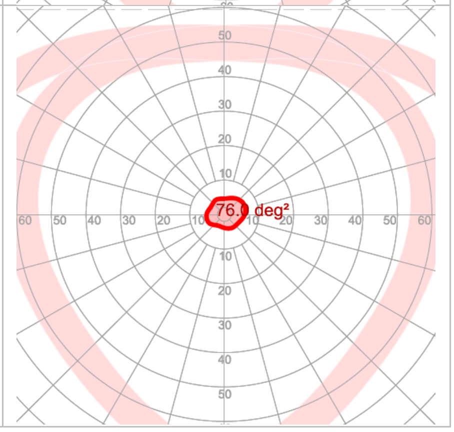
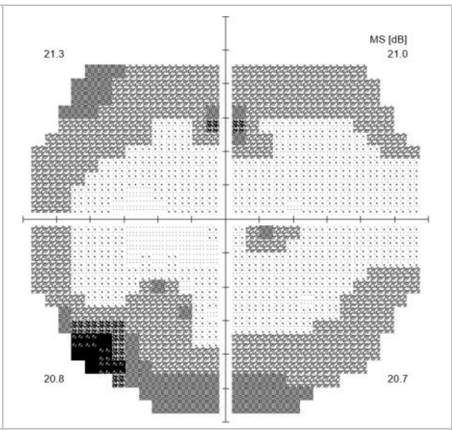
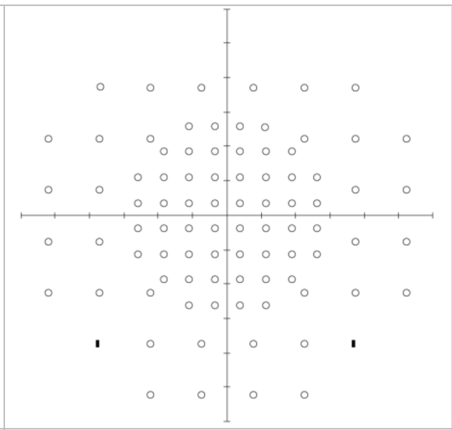
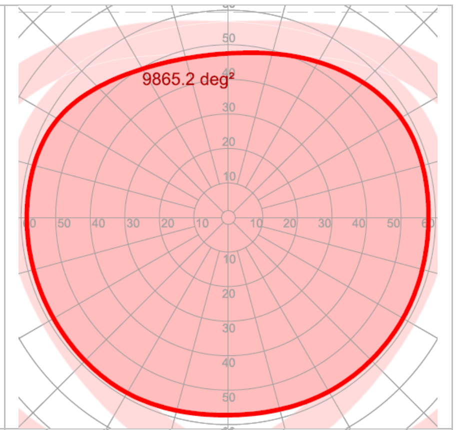
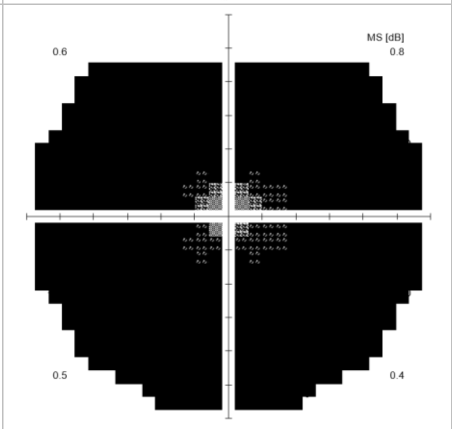
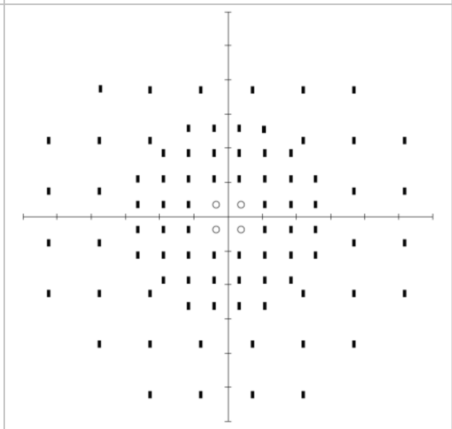
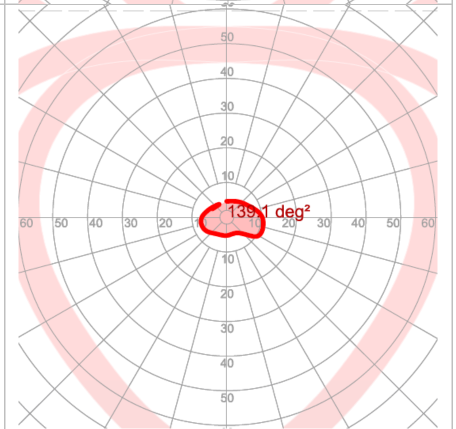
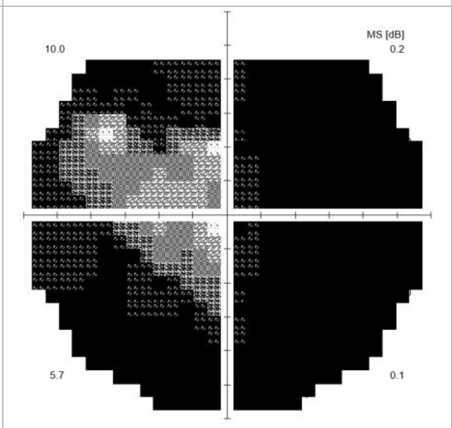
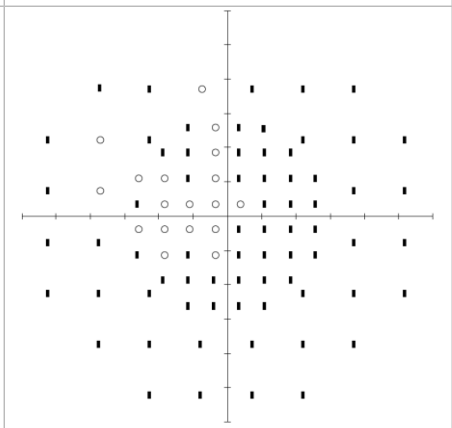
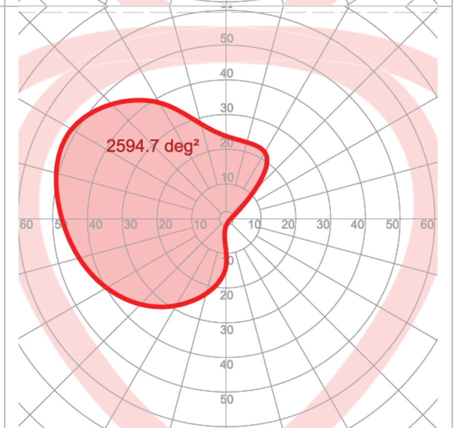
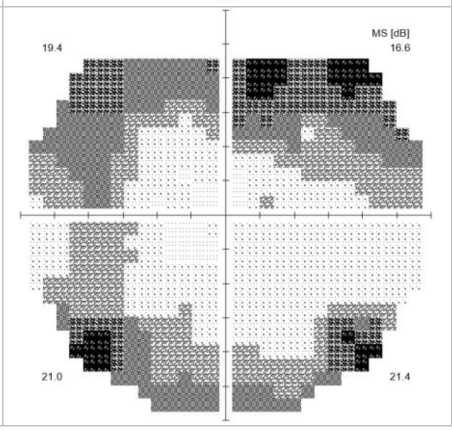
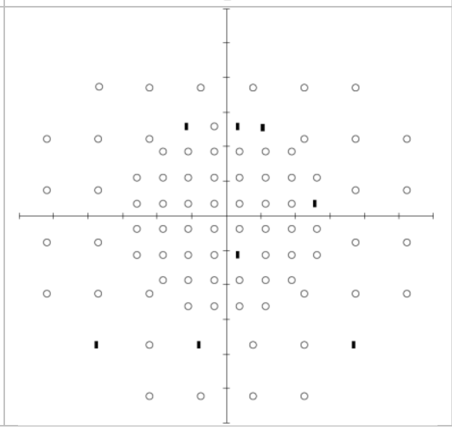
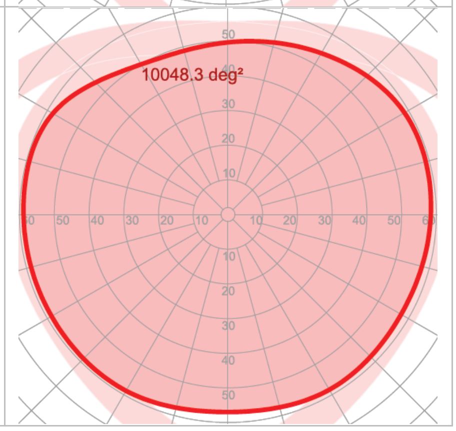
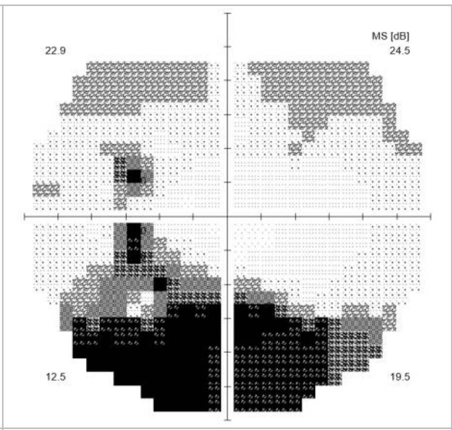
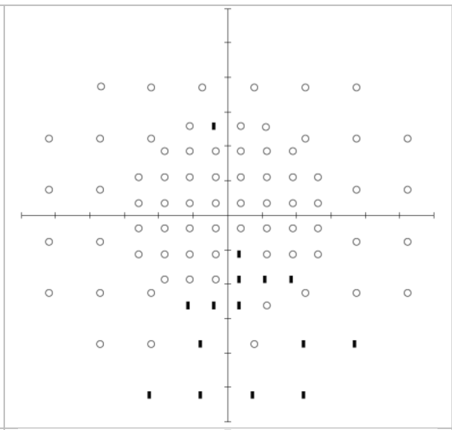
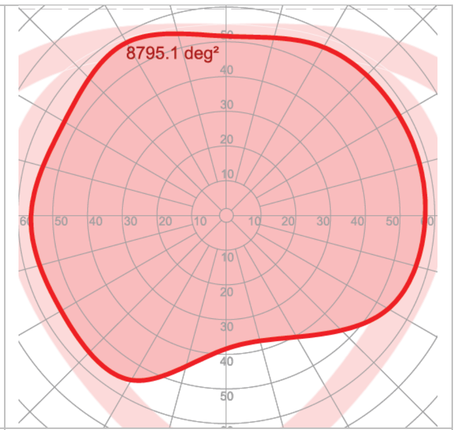
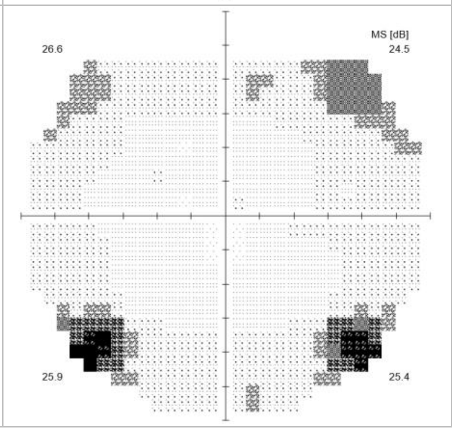
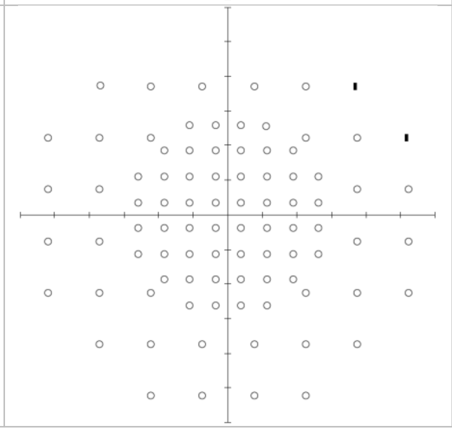
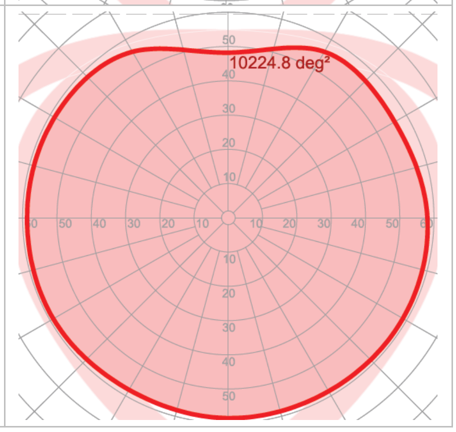
44	 MS [dB] 5.4 5.4 5.4 5.3		 10295.4 deg²
45	 MS [dB] 0.6 1.6 0.5 0.6		 240.6 deg²
46	 MS [dB] 0.2 0.0 0.3 0.5		 454.0 deg²
47	 MS [dB] 1.0 1.0 0.1 0.3		 76.0 deg²

48	MS [dB] 21.3 21.0 20.8 20.7		9865.2 deg²
49	MS [dB] 0.6 0.8 0.5 0.4		139.1 deg²
50	MS [dB] 10.0 0.2 5.7 0.1		2594.7 deg²
51	MS [dB] 19.4 16.6 21.0 21.4		10048.3 deg²

52	MS [dB] 22.9 24.5 12.5 19.5		8795.1 deg²
53	MS [dB] 26.6 24.5 25.9 25.4		10224.8 deg²

A2.5 Descriptive statistics of the FES-I scores (Chapter 8).

	Mean (±std)	**Median (25% IQ-75% IQ))**
Cleaning the house	1.36(±0.09)	1(1-2)
Getting dressed/ undressed	1.30(±0.09)	1(1-1)
Preparing simple meals	1.20(±0.09)	1(1-1)
Taking a bath or shower	1.62(±0.12)	1(1-2)
Going to the shop	1.92(±0.14)	2(1-3)
Getting in or out of a chair	1.26(±0.07)	1(1-1)
Going up or down stairs	2.34(±0.13)	2(2-3)
Walking around outside	2.08(±0.14)	2(1-3)
Reaching up or bending down	1.70(±0.12)	1(1-2)
Answering the telephone	1.36(±0.10)	1(1-2)
Walking on a slippery surface	2.88(±0.14)	3(2-4)
Visiting a friend/relative	1.86(±0.13)	2(1-2)
Going to a place with crowds	2.14(±0.16)	2(1-3)
Walking on an uneven surface	2.62(±0.13)	3(2-3)
Walking up or down a slope	2.16(±0.14)	2(1-3)
Going out to a social event	1.82(±0.13)	2(1-2)

Appendix 3: Supporting publications

A3.1 Journal articles

Subhi, H., Latham, K (2018). Visual field assessment in low vision. *Optometry in Practice.*

Subhi, H, Latham, K., Myint, J. and Crossland, M. (2017). Functional visual fields: a cross-sectional UK study to determine which visual field paradigms best reflect difficulty with mobility function. *BMJ Open. 7(11):e018831.*

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2017). Functional visual fields: relationship of visual field areas to self-reported function. *Ophthalmic Physiol Opt*.

A3.2 Conference presentations

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2014). Functional Visual Fields in Low Vision. *Faculty of Science & Technology 4th Annual Research Conference*. Cambridge, UK. May 2014.

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2014). Functional Visual Fields in Low Vision *8th Annual Research Student Conference.* Chelmsford, UK. June 2014.

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2015). Towards a Functional Visual Field Assessment for Low Vision. *Optometry Tomorrow*. Brighton, UK. March 2015.

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2015). Superior vs Inferior Visual Field: Which is More Important For Mobility Function? *9th Annual Research Student Conference.* Chelmsford, UK. June 2015.

Subhi. H., Latham. K., Myint, J. and Crossland, M. (2015). Superior vs Inferior Visual Field: Which is More Important for Mobility Function? *Faculty of Science & Technology 5th Annual Research Conference*. Chelmsford, UK. July 2015.

Subhi, H., Latham., K, Myint, J. and Crossland, M. (2015). Towards a Functional Visual Field Assessment for Low Vision. *British Congress of Optometry & Visual Science*. London, UK. September 2015.

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2015). Towards a Functional Visual Field Assessment for Low Vision. *European Society For Low Vision Research And Rehabilitation*. Oxford, UK. September 2015.

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2016). Visual Field Paradigms for Assessing Functional Field Loss. *10th Annual Research Student Conference.* Chelmsford, UK. June 2016.

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2016). Visual Field Paradigms for Assessing Functional Field Loss. *British Congress of Optometry & Visual Science.* Ulster, UK. September 2016.

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2016). Visual Field Paradigms for Assessing Functional Field Loss. *22nd International Visual Field Imaging Symposium*. Udine, Italy. September, 2016.

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2017). Visual Field Paradigms for Assessing Functional Field Loss. *Optometry Tomorrow*. Birmingham, UK. March 2017.

Subhi, H., Latham, K, Myint., J. and Crossland, M. (2017). Visual Field Paradigms for Assessing Functional Field Loss. *Faculty of Science & Technology 7th Annual Research Conference*. Chelmsford, UK. May 2017.

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2017). Functional Visual Fields 1: Visual Field Paradigms for Assessing Functional Field Loss. *Vision 2017. Low vision rehabilitation: a global right.* June 2017.

Latham, K., Subhi, H., Myint, J. and Crossland, M. (2017). Functional Visual Fields 2: Utilisation in Low Vision Practice. *Vision 2017. Low vision rehabilitation: a global right.*. June 2017.

Subhi, H., Latham, K., Myint, J. and Crossland, M. (2017). Functional visual fields 3: Relationship of Visual Field Areas to Self-Reported Function. *Vision 2017. Low vision rehabilitation: a global right.* June 2017.

Functional Visual Fields in Low Vision

Hikmat Subhi[1,2], Dr Keziah Latham[1,2], Dr Joy Myint[1,2], Dr Michael Crossland[2,3]

Abstract

Optometrists often encounter patients with peripheral visual field loss, which affects ability in visual and other tasks including mobility. The aim of this PhD project is to determine the most appropriate methods to assess peripheral functional visual fields in people with low vision, and to relate the extent of visual field loss to functional difficulties, as there is currently no visual field test that is optimised for assessing functional consequences of visual field loss.

The first experiment will aim to determine the extent to which visual fields should be assessed, and the locations of the visual field which best reflect self-reported vision related difficulties. The second experiment will aim to determine the most appropriate method of assessing peripheral visual fields in the low vision assessment by comparing different visual field protocols.

Introduction

Restricted visual fields have significant effects on the ability to undertake visual tasks and on mobility [1]. Visual impairment is also one of the most significant risk factors associated with falling [2].

We have previously shown that the sensitivity of the static binocular visual field between 10 and 30 degrees eccentricity is significantly related to self-reported difficulty in visual tasks; mobility in particular [1, 3]. However, it is unclear which locations are more important to reflect activities of daily living [3], and how to effectively assess functional visual fields in patients with low vision.

The Humphrey Field Analyzer II-i

Research Objectives

This patient centred study aims to:

1. Determine the most appropriate methods to assess peripheral functional visual fields in low vision patients
2. Relate the extent of visual field loss to functional difficulties.

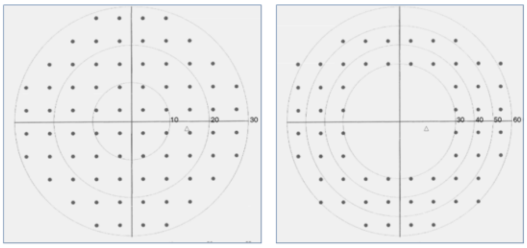
Research Methods

Experiment 1

The first experiment aims to determine the eccentricity to which visual fields should be assessed and the locations of the visual field which best reflect self-reported vision related difficulties.

We will:

- Binocularly assess visual fields using the Humphrey Field Analyzer 30-2 and 60-4 tests below.
- Conduct a face to face clinical interview using a modified version of the Activity Inventory[4] to assess self-reported visual difficulties.



The Central 30-2 Threshold and Peripheral 60-4 Threshold Test Patterns that will be used in Experiment 1

Experiment 2

The second experiment will aim to determine the most appropriate method of assessing visual fields in the low vision assessment by comparing different visual field protocols.

We hope to find a visual field test that:

- Relates well to self-reported visual difficulty
- Is acceptable to patients
- Demonstrates field loss easily to patients and others

References

1. Tabrett DR, Latham K. Inv Ophthalmol Vis Sci, 2011; 52: 5293–5302.
2. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Fall Prevention. J Am Geriatr Soc, 2001;49:664-672.
3. Tabrett DR, Latham K. Ophthal Physiol Opt, 2012: 32:156-163.
4. Bruijning J, van Nispen R, van Rens G. (2010). BMC Health Services Research. 10 (318), 1-10.

1. Visual Function and Physiology Research Group, Anglia Ruskin University. 2. Vision and Eye Research Unit, Anglia Ruskin University. 3. Moorfields' Eye Hospital, London.

hikmat.subhi@student.anglia.ac.uk

Anglia Ruskin University

Towards a Functional Visual Field Assessment for Low Vision

Hikmat Subhi[1,2], Keziah Latham[1,2], Joy Myint[3], Michael Crossland[4]

[1]Visual Function and Physiology Research Group, Anglia Ruskin University, [2]Vision and Eye Research Unit, Anglia Ruskin University, [3]Postgraduate Medicine, University of Hertfordshire , [4]Moorfields Eye Hospital, London

Funded by a College of Optometrists' Postgraduate Research Scholarship

Introduction

- Visual field loss is associated with:
  - Reduced mobility [1]
  - Reduced ability to read and watch TV [2]
  - Increased risk of falling [2]
- This patient centred study aims to:
  1. Relate the extent/areas of visual field loss to functional difficulties
  2. Determine the most appropriate method to assess peripheral functional visual fields in low vision patients

Figure 1. The Humphrey Field Analyzer II-i

Methods

- 41 participants with retinitis pigmentosa and glaucoma
- Binocular assessment of visual fields using the 30-2 and 60-4 SITA Fast programs on the Humphrey Field Analyser (Fig. 1, 2)
- Mean threshold within the central 0°-30° and peripheral 30°-60° was calculated
- Clinical interview using the Dutch Activity Inventory (D-AI) assessed self-reported visual related activity limitations (Fig. 3)
- Binocular visual acuity was determined using an EDTRS chart
- Binocular contrast sensitivity was assessed with a Pelli-Robson chart
- Central and peripheral visual field scores compared to D-AI scores in bivariate analyses

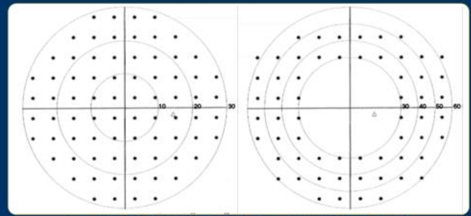


Figure 2. The Central 30-2 and Peripheral 60-4 Test Patterns

If important, how difficult is it for you: *

	0. Not important/NA	1. Not difficult	2. Slightly difficult	3. Moderately difficult	4. Very difficult	5. Impossible
to be able to move around in your home, without someone else's assistance?	○	○	○	○	○	○
to be able to move around indoors in unfamiliar surroundings, without someone else's assistance?	○	○	○	○	○	○
to be able to move/walk around outdoors without someone else's assistance? *	○	○	○	○	○	○
to be able to use public transportation? *	○	○	○	○	○	○

Figure 3: The questions used to assess self-reported mobility function

Results

- There is a strong correlation between the central and peripheral visual field scores ($r^2=0.77$, $p=.000$)
- Greater visual field loss (0-60 deg) is associated with greater self-reported difficulty ($r^2=0.38$; $p=.000$)
- The overall binocular visual field is in particular a good predictor of self-reported difficulties in mobility related activities ($r^2=0.58$, $p=.000$)
- The central and peripheral field areas are similarly correlated with overall self-reported function ($r^2=0.37$, $p=.000$ central, $r^2=0.34$, $p=.000$, peripheral)

Conclusion

- Both the central and peripheral fields are important to assess when considering functional ability
- The relationship between the overall visual field and self-reported difficulty is not greatly dependent on eccentricity
- Visual field loss is a good indicator of self-reported function, particularly mobility function
- The relationship may be dependent on how good the visual field is

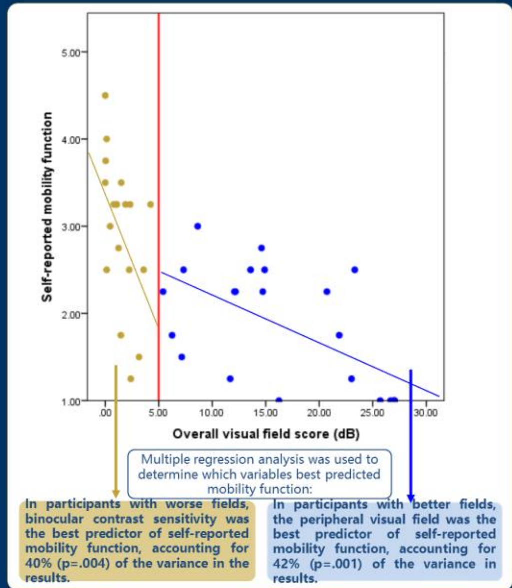


Figure 4. Graphical representation of the relationship between overall field score and self-reported mobility function

Future research

- We will use this information to determine the most appropriate method of assessing visual fields in the low vision assessment by comparing different visual field protocols
- This test will:
  - Reflect binocular visual function
  - Relate to objective and self-reported visual difficulty
  - Demonstrate field loss easily to patients and others

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Superior vs. Inferior Visual Field:
Which is more important for mobility function?

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Introduction

- Restricted visual fields have significant effects on mobility[1].
- Numerous studies have suggested the significance of the inferior visual field for mobility function[2-7].

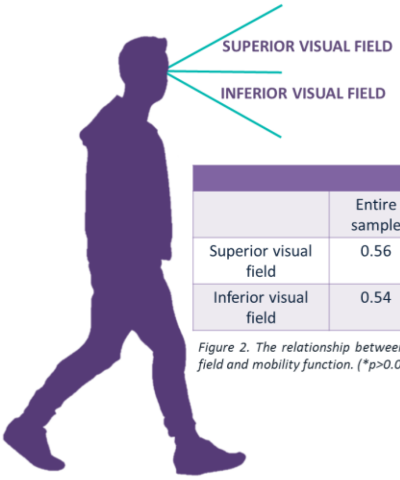
Methods

- 52 participants with visual field restriction undertook binocular assessment of visual fields out to 60 degrees from fixation.
- The average brightness of light just seen within different areas of the visual field was used as the main outcome measure for analysis.
- Participants with an overall visual field score of ≥10dB were defined as having 'better fields' and those with an overall field score of ≤10dB were defined are having 'worse fields'.
- 4 mobility-related questions from the Dutch Activity Inventory (D-AI) were used to determine perceived mobility function.
- Scores for different areas of the binocular field were compared to D-AI scores.

If important, how difficult is it for you:	0. Not important	1. Not difficult	2. Slightly difficult	3. Moderately difficult	4. Very difficult	5. Impossible
To be able to move around in your own home?						
To be able to move around indoors in unfamiliar surroundings?						
To be able to move/walk around outdoors?						
To be able to use public transport?						

Figure 1. The questions used to assess self-reported mobility function

Results



	Mobility Function		
	Entire sample	Better fields	Worse fields
Superior visual field	0.56	0.19*	0.43
Inferior visual field	0.54	0.45	0.42

Figure 2. The relationship between the superior and inferior visual field and mobility function. ($p>0.05$, for all others $p<0.001$)*

- For the entire sample, the superior and inferior visual fields are similarly correlated to mobility function.
- The inferior visual field is more significant than the superior visual field for mobility function only in individuals with better visual fields.

Conclusion

- Our results indicate the inferior visual field is more significant than the superior visual field for mobility function in individuals with less restricted visual fields.
- For those with greater visual field loss, the inferior and superior visual field are similarly correlated.

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1. Tabrett DR, Latham K. Inv Ophthalmol Vis Sci, 2011; 52: 5293–5302.
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VISUAL FIELD PARADIGMS FOR ASSESSING FUNCTIONAL FIELD LOSS

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Introduction

- Visual field loss is associated with:
  - Reduced mobility[1]
  - Increased risk of falling[2]
- This patient centred study aims to determine the most appropriate methods to assess functional visual fields in low vision patients.

Methods

- 50 participants with peripheral field loss
- Self-reported mobility function determined using the Independent Mobility Questionnaire (IMQ)
- 5 visual fields tests, 3 on Octopus 900:
  1. Custom binocular threshold
  2. Custom binocular supra threshold
  3. Custom binocular kinetic
- 2 on Humphrey Field Analyzer:
  4. Esterman
  5. Integrated monocular HFA 30-2 visual fields (IVF)
- Mean threshold, percentage of stimuli seen, and visual field area used as main outcome measures
- Visual field scores compared to IMQ scores in bivariate analyses

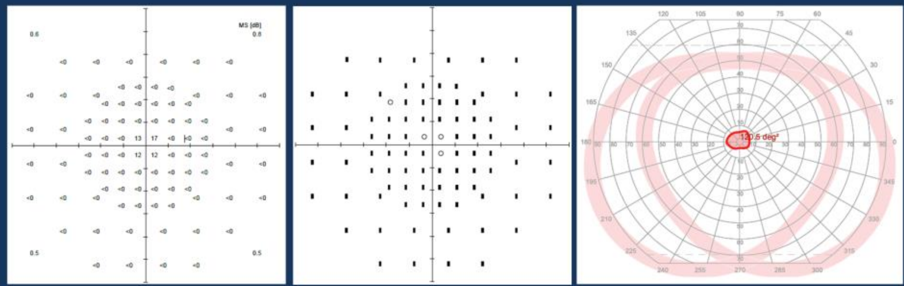

Figure 1. Binocular threshold, supra threshold, and kinetic visual field results of participant PB.

Results

- Greater visual field loss is similarly associated with greater self-reported mobility difficulty for all visual field scores.
- The quickest test was the binocular kinetic, while the longest were monocular threshold assessments (for IVF determination).
- The most favoured test was kinetic, while the IVF was ranked least favourite

	Mobility function (R^2)	Mean test duration (sec±sd)
Binocular threshold (dB)	0.47	7min 40sec (±21sec)
Binocular supra threshold (%)	0.47	3min 10sec (±23sec)
Binocular kinetic (deg²)	0.48	1min 26sec (±9sec)
Esterman (%)	0.46	6min 20sec (±19sec)
IVF (dB)	0.38	9min 23sec (±24 sec)

Table 1. Non parametric 2-tailed Spearman's correlations coefficients ($p \leq 0.001$ for all). Mean test durations are also shown.

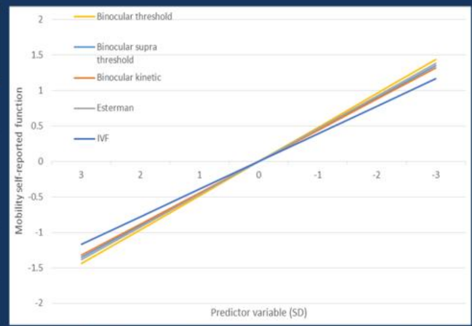

Figure 2. The linear association of visual field variables against self-reported mobility function.

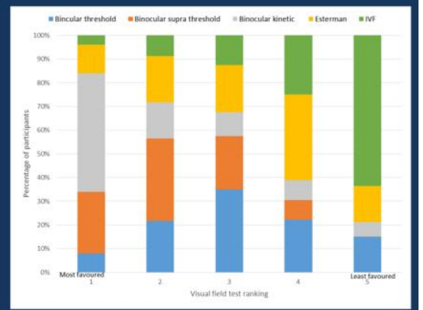

Figure 3. Participants' ranking of visual field tests acceptability.

Conclusion

- Binocular visual field tests can reflect self-reported mobility function
- While all five field assessments relate similarly to perceived function, the three custom tests and the Esterman explain a greater degree of variance in self-reported mobility function
- A binocular visual field test that does not ignore the peripheral 30-60 deg of the field is effective for reflecting functional difficulty
- A kinetic assessment of the visual field area may be quicker and as effective at predicting mobility function as static threshold assessment

References
[1]Tabrett DR, Latham K. Factors influencing self-reported vision-related activity limitation in the visually impaired. Inv Ophthalmol Vis Sci, 2011; 52: 5293–5302.
[2]Ramrattan RS, Wolfs RC, Panda-Jonas S, et al. Prevalence and caused of visual field loss in the elderly and associations with impairment in daily functioning: the Rotterdam Study. Arch Ophthalmol 2001;119:1788-1794

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Functional Visual Fields 3: Relationship of Visual Field Areas to Self-Reported Function

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Introduction

- Visual field loss is associated with:
  - Reduced mobility[1]
  - Increased risk of falling[2]
- The mean threshold of a binocular visual field to 60° eccentricity is a good predictor of mobility function[3]
- The aim of this study is to determine the locations within the visual field and the methods of assessment that best reflect functional difficulty with mobility tasks

Methods

- 50 participants with peripheral field loss
- Self-reported mobility function determined using the Independent Mobility Questionnaire (IMQ)
- 5 visual fields tests, 3 on Octopus 900 (Fig 1):
  1. Custom binocular threshold
  2. Custom binocular supra threshold
  3. Custom binocular kinetic
- 2 on Humphrey Field Analyzer:
  4. Esterman
  5. Integrated monocular HFA 30-2 visual fields (IVF)
- Visual field data was divided into:
  - Central (0-30 deg) and peripheral (30+ deg) areas
  - Finer 10 degree divisions also made
  - Superior and inferior visual field areas
- Mean threshold, percentage of stimuli seen, and VF extent used as main outcome measures
- Visual field scores compared to IMQ person measures in bivariate analysis
- Binary responses to the 35 task questions of the IMQ were used to compare different visual field areas in ROC analysis

Results

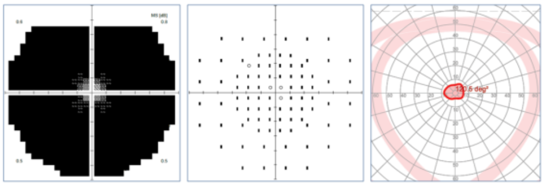

Fig 1. Binocular threshold, suprathreshold & kinetic visual field results of participant PB.

- Central and peripheral visual field areas were similarly related to mobility self-reported function for all tests assessing beyond 30 degrees (R^2=0.33-0.45, $p<0.001$ for all)
- Peripheral threshold field score was significantly better than central at predicting difficulty with two mobility tasks
- Superior and inferior field areas were both significantly related to self-reported mobility function for all field paradigms (R^2=0.33-0.52, $p<0.001$ for all) with a tendency for inferior field to be more strongly correlated
- Inferior visual field score was significantly better than superior at predicting difficulty with five mobility tasks (Fig 3)

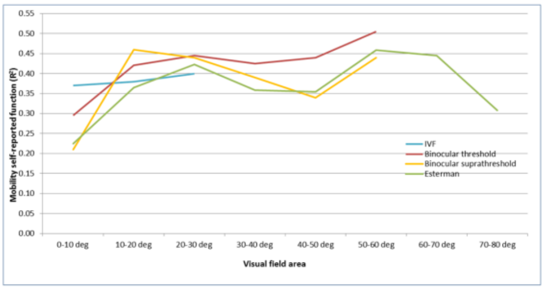

Fig 2. Graphical representations of the relationship between visual field areas and self-reported function for the different visual field assessments.

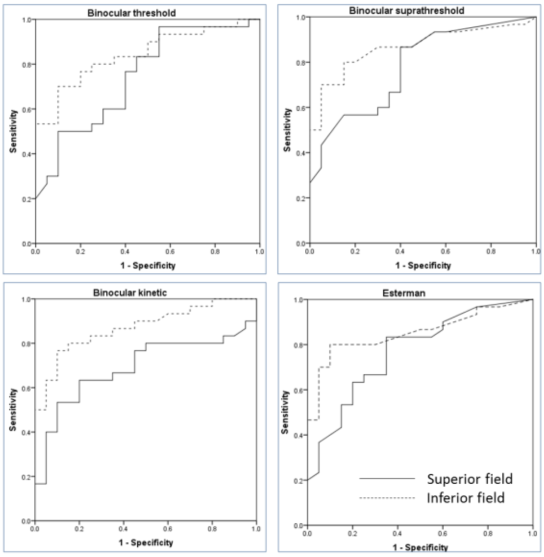

Fig 3. ROC curves describing the relative performance of superior and inferior visual field scores in predicting self-reported difficulty avoiding bumping into knee height objects. The inferior visual field was significantly better than superior at predicting difficulty with this task for four visual field scores.

Conclusions

- Both peripheral and central visual field areas have a role in reflecting the functional difficulties of people with field loss and should be considered in a functional visual field assessment
- The significance of the inferior field to mobility function is demonstrated regardless of how the visual field is assessed

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