A Study to Develop a New Clinical Measure to Assess Visual Awareness in Tunnel Vision

A thesis submitted to The University of Manchester for the degree of Doctor of Philosophy in the Faculty of Life Sciences

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Ali Mazyed Alshaghtrah
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Abstract

Visual conditions such as retinitis pigmentosa and Usher syndrome can gradually cause tunnel vision. Patients with these conditions usually face difficulties with navigation, avoiding obstacles, and performing visual search. Loss of mobility can affect patients’ independence and quality of life. One of the rehabilitation strategies for patients with tunnel vision is the use of optical aids to enhance mobility performance. The main method used to evaluate the usefulness of optical aids is the patient’s subjective report after extended wear. In order to evaluate optical aid effectiveness in the clinic, a new test based on the visual search paradigm was designed to assess the patient's visual awareness. This was named the assessment of visual awareness (AVA) test. The main aim of this study was to develop the AVA test, establish its sensitivity, validity and repeatability, and then use it to investigate the efficacy of optical aids in this group of people.

The AVA test consists of 32 peripheral targets presented at four different locations: 1st annulus (at 5° from the central fixation), 2nd annulus (10°), 3rd annulus (20°) and 4th annulus (30°). In this study, the peripheral targets were presented singly against a spatial noise background in a presentation area of 81° H × 62° V. Participants were allowed to use head and eye movements and were asked to search for and locate each target. The detection time (DT) was recorded. A new, sensitive and easy to set up indoor mobility course was also designed and validated prior to its use in validating the AVA test.

A total of 50 normally sighted participants with simulated tunnel vision (TV) (5° to 20°, in 5° steps) and 20 patients with TV (retained field 4° to 21°) were tested. The AVA test was found to be responsive to the change in field of view (FoV) and to the target locations in both groups of participants. In the simulated group, a significant relationship was found between FoV and DT at each annulus (r ranging from -0.55 to -0.77, p < 0.0001). A significant relationship was found between target location and DT within each FoV size (20°, 15°, 10° and 5°) (r ranging from 0.53 to 0.84, p < 0.0001). In the TV patients, a statistically significant relationship was found between FoV and DT at each annulus (r range from -0.40 to -0.60, p < 0.05). The target location was shown to have a significant relationship with the DT within each FoV size (r ranging from 0.50 to 0.60, p < 0.05). Finally, the AVA test was found to be significantly related to the simulated TV participants' performance on the indoor mobility course.

The AVA test was used to assess the efficacy of three optical aids: the partial aperture prism (10 patients), the Tri-field prism (10 patients) and the reverse telescope (4 patients). The AVA test showed no significant improvement in DT with either of the prisms and the participants did not find these aids helpful. DT with the reverse telescope improved, but none of the participants were willing to use these on extended trial. The AVA test gave clear indications of the efficacy of each aid, a result which could affirm the importance of the AVA test.

In conclusion, the AVA test was found to be sensitive, valid and repeatable. DT did not improve in either of the optical aids which were found to be unsuccessful, suggesting that the AVA could be a promising clinical test. However the aids which showed improved DT were not evaluated over the longer term, and therefore did not allow full evaluation of the AVA test.
Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.
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Dedication

This work is dedicated to my parents, who have looked after me throughout my life and for their unconditional support and encouragement during my time in Manchester. To my wife Eman, for sharing the good times and bearing the bad times away from home and for looking after our two children Ranem and Yousef. To my children, for offering happy moments in a place away from home.

To my brothers and sisters, Ahmad, Abdullah, Muza, Nora and Nada, who believed in me and for loving me. To them for being there for me whenever I needed their support and advice.

To all my friends here in Manchester and in the UK, for their help in getting through the difficult times abroad and for the great times we have had in Manchester.
### List of Abbreviations

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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADL</td>
<td>Activities of daily living</td>
</tr>
<tr>
<td>AFOV</td>
<td>Attended field of view</td>
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<td>AMD</td>
<td>Age-related macular degeneration</td>
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<td>ANCOVA</td>
<td>Analysis of covariance</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
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<tr>
<td>AVA</td>
<td>Assessment of visual awareness</td>
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<tr>
<td>BRPS</td>
<td>British retinitis pigmentosa society</td>
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<td>BVD</td>
<td>Back vertex distance</td>
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<td>cd</td>
<td>Candela</td>
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<td>CE</td>
<td>Collision envelope</td>
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<td>CFL</td>
<td>Central field loss</td>
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<tr>
<td>CS</td>
<td>Contrast sensitivity</td>
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<td>DE</td>
<td>Detection efficiency</td>
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<td>DT</td>
<td>Detection time</td>
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<td>ERG</td>
<td>Electroretinography</td>
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<td>FE</td>
<td>Field expander</td>
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<tr>
<td>FFS</td>
<td>Functional field score</td>
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<td>FoV</td>
<td>Field of view</td>
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<td>HRQoL</td>
<td>Health related quality of life</td>
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<tr>
<td>ICF</td>
<td>International Classification of Functioning, Disability and Health</td>
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<tr>
<td>ICIDH</td>
<td>The International Classification of Impairment, Disability, and Handicaps</td>
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<tr>
<td>IMQ</td>
<td>Independent mobility questionnaire</td>
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<td>IPD</td>
<td>Inter-Pupillary distance</td>
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<td>IQR</td>
<td>Interquartile range</td>
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<tr>
<td>LE</td>
<td>Left eye</td>
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<tr>
<td>LoA</td>
<td>Limit of agreement</td>
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<td>LV</td>
<td>Low vision</td>
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<td>LVAs</td>
<td>Low vision aids</td>
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<td>LVQOL</td>
<td>Low vision quality of life</td>
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<td>M and PFL</td>
<td>Mid and peripheral field loss</td>
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<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>NEI-VFQ</td>
<td>National eye institute visual function questionnaire</td>
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<td>NSG</td>
<td>Non-sighted guide technique</td>
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<tr>
<td>O&amp;M</td>
<td>Orientation and Mobility</td>
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<tr>
<td>PDM</td>
<td>Percentage deviation from the median</td>
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<td>PDR</td>
<td>Proliferative diabetic retinopathy</td>
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<td>PPWS</td>
<td>Percentage preferred walking speed</td>
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<td>PSPD</td>
<td>Perceived safe passing distance</td>
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<td>PVC</td>
<td>Polyvinyl chloride</td>
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<tr>
<td>PWS</td>
<td>Preferred walking speed</td>
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<td>Quality of life</td>
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<tr>
<td>RE</td>
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<td>RP</td>
<td>Retinitis Pigmentosa</td>
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<td>RPE</td>
<td>Retinal Pigment Epithelium</td>
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<td>Reaction Times</td>
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<td>Reverse Telescope</td>
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<td>SG</td>
<td>Sighted Guide</td>
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<tr>
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<td>Sight Impaired</td>
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<td>TVPs</td>
<td>Patients with Tunnel Vision</td>
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<td>UFOV</td>
<td>Useful field of view concept</td>
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<td>URL</td>
<td>Universal resource locator</td>
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<tr>
<td>VA</td>
<td>Visual acuity</td>
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<tr>
<td>VDD</td>
<td>Visual detection distance</td>
</tr>
<tr>
<td>VF</td>
<td>Visual field</td>
</tr>
<tr>
<td>VI</td>
<td>Visual impairment</td>
</tr>
<tr>
<td>VRE</td>
<td>Virtual reality environment</td>
</tr>
<tr>
<td>VRQoL</td>
<td>Vision related quality of life</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
</tr>
</tbody>
</table>
1.1 Literature Review Methodology

To identify articles relevant to this study, searches of two well recognized bibliographic databases were performed. The first database was the ISI Web of Knowledge platform which includes the Web of Science and Medline. Web of Science contains various databases, such as the Science Citation Index (expanded with cited references; from 1970 to present) and the Conference Proceedings Citation Index - Science and Technical edition (from 1990 to present). Medline, the second ISI Web of Knowledge database, is linked with the National Library of Medicine in the United States. Medline covers literature from 1950 to the present and contains approximately 5200 journals from the United States and more than 80 other countries. The second bibliographic database was PubMed which covers some old Medline citations that have not yet been updated with current terms and converted to Medline status. PubMed comprises more than 18 million journal citations from 1948 to the present for biomedical articles from Medline and life science journals.

The terms used to search for the optical aids were: reverse telescope, peep-hole telescope, amorphic lenses, InWave prism, Gottlieb system, prism, field expander, and field enhancement. To search for papers focusing on the assessment of mobility performance, the terms used were: mobility enhancement, mobility ability, mobility, travelling, and walking speed. The papers that investigated the visual search ability in tunnel vision were searched for and terms used were: visual search, scanning, useful field of view. The terms used to search for questionnaire articles were: daily activity, quality of life, low vision rehabilitation, visual function questionnaire, vision related quality of life, visual questionnaire, and functional assessment. In order to refine these searches each of these terms was combined with one of these additional phrases: low vision, vision (visual) disability, visual impairment, partially
sighted, RP, tunnel vision and visual field loss (or restriction). Furthermore, to ensure that the searches were comprehensive, related references in these papers were also reviewed.

1.2 Definitions of Low Vision

Visual impairment (VI), low vision (LV), and partial sight may broadly be defined as terms which indicate a reduction in visual acuity (VA) that cannot be corrected with ordinary lenses to equal the VA for a typical person of the same age (Dickinson, 1998). However, VI has multiple definitions according to the context in which it is used. The World Health Organization (WHO) defines a person with LV as "one who has impairment of visual functioning even after treatment and/or standard refractive correction, and has a VA of less than 6/18 to light perception, or a visual field (VF) of less than 10° from the point of fixation, but who uses, or is potentially able to use, vision for planning and/or execution of a task". This definition was intended to be used worldwide for reporting purposes and was not intended to be used as a measure of eligibility for a service or facility.

Every country has developed its own legal requirements for an individual to be certified as partially sighted or blind. That means that a patient's VA and/or VF must be below a certain level in order to be certified as partially sighted or blind (Dickinson, 1998). In England and Wales the legal definition of the blind person is "so blind as to be unable to perform any work for which eyesight is essential" (the National Assistance Act 1948, section 64 (1)). Partial sight is defined as "substantially and permanently handicapped by defective vision caused by congenital defect, illness, or injury". In these definitions the eyesight only is taken into account, and is measured by VA, with VF taken into consideration.

These definitions are general and could be interpreted in many ways (Dickinson, 1998).
Therefore, the criteria used in the certificate of vision impairment (CVI) were more specific. The newest CVI form was updated in 2005 and certifies a patient as a partially sighted or as blind (nowadays using the preferred terminology "sight impaired" (SI) or "severely sight impaired" (SSI), respectively) (Royal College of Ophthalmologists, 2013). The specific criteria for the CVI are:

**Severely sight impaired:**
3/60 Snellen or worse
6/60 Snellen or worse with markedly restricted field

**Sight impaired:**
3/60 to 6/60 Snellen with full VF
Up to 6/24 Snellen or worse with moderated field constriction, opacities in media or aphakia.
6/18 Snellen or better with gross field defect, for example hemianopia, or if there is a marked contraction of the VF, for example in retinitis pigmentosa (RP) or glaucoma.

Terms such as visual disability and visual handicap are not accurate synonyms for SI or SSI. This is because they indicate different meanings to the other terms (World Health Organization, 1994) (Table 1.1). The International Classification of Impairment, Disability, and Handicaps (ICIDH), which was published in 1980, tried to differentiate these terms from a functional perspective (Dickinson, 1998) (Table 1.2). According to this classification, impairment and disability are essential requirements in the definition of the handicap (Kearney and Pryor, 2004). However, the ICIDH has suffered from cultural bias in some of the language used (lack of clarity, insufficient attention to the role of the environment, and the classification being based on medical dysfunction (Kearney and Pryor, 2004)). Therefore,
the WHO revealed in 2001 the new International Classification of Functioning, Disability and Health (ICF) (Table 1.2).

The WHO ICF classification is not based on disease consequences, but on health components in general (Kearney and Pryor, 2004). Additionally, the new definition represents the interaction between function and disability, i.e. body function, activity and participation, and contextual factors, i.e. environmental and personal factors (Kearney and Pryor, 2004). More specifically, according to the WHO ICF classification, a disability is considered as an activity limitation and is an umbrella term "to denote a multidimensional phenomenon resulting from the interaction between people and social environment" (World Health Organization, 2001). Further, the handicap is now referred to as participation restriction and could be defined as "the nature and the extent of a person’s involvement in life situations in relation to impairment, activities, health condition, and contextual factors" (World Health Organization, 2001).
Table 1.1 The description of impairment, disability, and handicap as adopted by WHO in the International Statistical Classification of Diseases (WHO, 1994)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Concerned with</th>
<th>Represents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impairments</td>
<td>Abnormalities of body structure and appearances, organs or system functioning</td>
<td>Disturbances at organ level</td>
</tr>
<tr>
<td>Disabilities</td>
<td>Impairment in terms of functional performance and activities</td>
<td>Disturbances at personal level</td>
</tr>
<tr>
<td>Handicaps</td>
<td>Disadvantages resulting from impairment and disabilities</td>
<td>Interaction with and adaptation to individual's surroundings</td>
</tr>
</tbody>
</table>

Table 1.2 The definition of impairment, disability, and handicap according to the WHO in the context of health (Kearney and Pryor, 2004)

<table>
<thead>
<tr>
<th>The ICIDH definition according to the WHO in 1980</th>
<th>The ICF definition according to the WHO in 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Impairment:</strong> any loss or abnormality of psychological, physiological, or anatomical structure or function. <strong>Disability:</strong> any restriction or lack (resulting from impairment) of ability to perform an activity in the manner or within the range considered normal for a human being. <strong>Handicap:</strong> a disadvantage for a given individual, resulting from impairment or disability that limits or prevents the fulfilment of a role that is normal (depending on age, sex and social and cultural factors) for that individual.</td>
<td><strong>Body functions:</strong> the physiological functions of the body systems (including psychological functions). <strong>Body structures:</strong> the anatomical parts of the body such as organs, limbs and their components. <strong>Impairments:</strong> problems in body function or structure such as significant deviation or loss. <strong>Activity:</strong> the execution of a task or action by an individual. <strong>Participation:</strong> involvement in a life situation. <strong>Activity limitations:</strong> difficulties an individual may have in executing activities. <strong>Participation restrictions:</strong> problems an individual may experience in involvement in life situations. Environmental factors make up the physical, social and attitudinal environment, in which people live and conduct their lives.</td>
</tr>
</tbody>
</table>
VA and VF are commonly used to classify the severity of VI. For example, in 2010 the WHO classified the severity of VI based on VA and the extent of the horizontal VF (Table 1.3). However, these measures indicate only the state of VI but do not necessarily reflect the ability (or disability) to perform certain tasks. In spite of this the visual disability could be used to indicate the severity of impairment (Dickinson, 1998). Additionally, from a clinical standpoint, the ability (or inability) to perform certain tasks is difficult to quantify, with the exception of the reading task which is routinely assessed in LV clinics. It is necessary for the reading task to be performed in order to assess the extent of the visual disability in everyday tasks (Dickinson, 1998). Thus, particularly in research, the ability, or inability, to perform certain tasks is generally assessed by a subjective method, such as the visual function questionnaire.

Table 1.3 The visual impairment (VI) categories according to the International Statistical Classification of Diseases and Related Health Problems, 10th revision (ICD-10) version for 2010 (World Health Organization, 2010)

<table>
<thead>
<tr>
<th>Category of visual impairment</th>
<th>Visual acuity with best possible correction</th>
<th>Or central visual field*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0: Mild or no VI</td>
<td>Worse than</td>
<td>Equal to or better than</td>
</tr>
<tr>
<td>1: Moderate VI</td>
<td>6/18</td>
<td>6/18</td>
</tr>
<tr>
<td>2: Severe VI</td>
<td>6/60</td>
<td>3/60</td>
</tr>
<tr>
<td>3: Blindness</td>
<td>3/60</td>
<td>1/60 (or CF* at 1 metre)</td>
</tr>
<tr>
<td>4: Blindness</td>
<td>1/60 (or CF at 1 metre)</td>
<td>Light perception</td>
</tr>
<tr>
<td>5: Blindness</td>
<td></td>
<td>No light perception</td>
</tr>
<tr>
<td>9: Undetermined or Unspecified</td>
<td>Undetermined or unspecified</td>
<td></td>
</tr>
</tbody>
</table>

* VF restriction criteria applicable even if VA is better than for that category of VI, CF refers to counting finger, and VF refers to visual field.
In this thesis, VI and LV will be used to indicate the decline of the VA and/or VF. In addition, the term disability will be used to indicate the inability to perform certain tasks (mainly associated with orientation and mobility) as a result of certain visual conditions (i.e. TV).

1.3 Tunnel Vision

The loss of the peripheral VF with the retention of the central field is widely known as tunnel vision (TV): this loss results in a constricted circular tunnel-like VF. Several conditions could cause TV, including glaucoma, RP and Usher syndrome (a genetic disorder causing RP in conjunction with differing degrees of hearing loss). The latter two conditions have a distinct feature in comparison to glaucoma, which is that they preserve a relatively good VA in the moderate and advanced stages (Herse, 2005, Grover et al., 1997a, Grover et al., 1999).

In detail, RP can be defined as a retinal degenerative disease whereby intra-retinal pigment deposits occur as a result of retinal pigment epithelium (RPE) cells migrating to the neural retina (Hartong et al., 2006). This causes primary degeneration of the rods and also affects the cones (Hamel, 2006, Hartong et al., 2006). The pigment deposits usually start in the mid periphery of the retina where the rods are normally highly concentrated. This corresponds to the area of VF loss. The decline of the VF is approximately 2.6% to 13.5% annually and of the electroretinogram (ERG) approximately 8.6% to 18.5% (Hartong et al., 2006). In the advanced stages the patient will already have lost most of the VF, and only a few central degrees of the central field of view (FoV) will be retained. In the latter stages of the disease the patient may have total loss of vision (usually by the age of 60) (Hartong et al., 2006, Berson, 1993). Generally, RP can be divided into three stages: early, mid, and advanced (Hamel, 2006, Hartong et al., 2006, Berson, 1993). The prevalence of RP is approximately 1
in 4000 people with a worldwide prevalence of between 1 and 1.5 million people (Hamel, 2006, Hartong et al., 2006, Berson, 1993). Most of these patients are registered legally blind by the age of 40 due to a severely constricted VF (Hartong et al., 2006, Berson, 1993).

1.3.1 RP Signs and Symptoms

Patients with RP experience various signs and symptoms that range from the barely noticeable to severe impairment over the duration of the disease, which can span several decades due to its slow progression (Hamel, 2006, Berson, 1993). These symptoms, once they have appeared, will persist throughout the course of the disease (Hamel, 2006, Hartong et al., 2006, Berson, 1993). However, the signs and symptoms are related to the stages of the disease. In the early stage the symptoms include night blindness (or nyctalopia), photophobia (in some cases), stable VA and normal colour vision. In the mid stage the patient experiences moderate loss to stable VA, loss of colour vision (patients often have a tendency to lose the discrimination of blue and yellow hues), poor light adaptation, photophobia, difficulty driving and walking at night, and difficulty seeing objects in the periphery. Finally in the advanced stage the patient suffers reduced VA to different degrees, and classical TV.

Clinical signs of RP vary according to the stage of the disease (Hamel, 2006, Hartong et al., 2006, Berson, 1993). In the early stage the clinical features include: scattered field loss in the mid-periphery area of the VF (documented by perimetry), moderately attenuated retinal vessels, and normal optic disc and decline of b-wave amplitude (documented by the ERG). In the mid-stage the features include ring shape scotoma in the mid periphery, progressing both inwards and outwards; intra-retinal pigmented deposits taking the shape of black bone spicules; reduced contrast sensitivity (CS) (Alexander et al., 1992); attenuated retinal vessels; sub-capsular posterior cataract (the incidence of cataract is approximately 50%); pale optic
disc; retinal atrophy in some areas, and dramatic decline in a and b-wave amplitudes (in the ERG) (Figure 1.1). In the advanced stage the features include: widespread intra-retinal pigmentary deposits up to the macula; thin retinal vessels; chorio-retinal atrophy in the periphery and in the foveo-macular area; waxy pallor of the optic disc; ERG un-recordable and classical TV. Finally, the patient will lose the central FoV and in some cases, will only be able to perceive light in the peripheral field (Hamel, 2006, Berson, 1993).

![Fundus photograph of one of our RP patients in the mid-advanced stage (not dilated). The black bone spicule-shaped pigment deposits are present in the mid periphery along with retinal atrophy, retinal vessels are attenuated and pale optic disc is found.](image)

One of the fundamental clinical features of RP is VF loss. Several studies suggest grading the VF loss from 0 to 6 as described in Table 1.4 and Figure 1.2. (Grover et al., 1997b, Heckenlively and Krauss, 1988, Ijima et al., 1986).

**Table 1.4 The classification of VF defects in RP patients**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Normal VF</td>
</tr>
<tr>
<td>1</td>
<td>Some scattered scotomas in the mid periphery.</td>
</tr>
<tr>
<td>2</td>
<td>Ring scotoma around the mid periphery.</td>
</tr>
<tr>
<td>3</td>
<td>Restricted VF within the central 30°.</td>
</tr>
<tr>
<td>4</td>
<td>Restricted VF within the central 15° with isolated peripheral visual islands.</td>
</tr>
<tr>
<td>5</td>
<td>Restricted VF within the central 15° without peripheral visual islands.</td>
</tr>
<tr>
<td>6</td>
<td>Restricted VF within the central 10°.</td>
</tr>
</tbody>
</table>
Figure 1.2 The classification of VF defects in RP patients (Sugawara et al. 2009)

In Figure 1.2, the black spot in Grades 0 to 3 show the blind spot, Grade 1 shows the scattered scotomas in the mid periphery, and Grade 2 the ring scotoma around the mid periphery is present. Grade 3 shows the scotoma around the central $30^\circ$ and there is a superior functioning island. In Grade 4 the central field is constricted to $15^\circ$ with isolated peripheral visual islands. In Grade 5 the central $15^\circ$ is intact and there are no peripheral islands. In Grade 6 VF is restricted within the central $10^\circ$.

1.3.2 Potential Treatment for RP

Currently, there are no medical/surgical treatments to stop the progression of RP or to restore vision. However, several strategies have been suggested for slowing the progression of the disease.

To begin with, data from animal studies and clinical evidence suggest that RP is partly light dependent (Wang et al., 1997). This suggests that light may increase the rate of photoreceptor death. Thus, wearing sunglasses while outside may slow disease progression. In particular,
yellow-orange spectacles are often used to minimize photophobia. In addition, the avoidance of sunlight dazzling the eyes from the side would also be beneficial (Hamel, 2006, Hartong et al., 2006). Vitamins A and E are also thought to help slow disease progression. The antioxidant effects of these two vitamins may slow the rate of death of the photoreceptors (Hamel, 2006, Hartong et al., 2006). However, a randomised controlled trial showed that vitamin E may cause adverse effects in the disease (Eliot et al., 1993). However, vitamin A has shown significant success in some clinical studies as it appears to slow the decline in cone amplitude as seen by ERG (Hamel, 2006, Hartong et al., 2006, Eliot et al., 1993). However, the VA and the VF do not show a significant change. Therefore, it seems that more clinical studies are needed to provide evidence to support these suggestions.

Many other approaches have been suggested to treat RP, and could be considered as potential future treatments as they are still being investigated or have been found to show only minimal improvement. The first approach is gene therapy, which attempts to identify the genes responsible for RP and to introduce a healthy version of that gene into the diseased tissue. This would enable the gene to produce the missing protein. This approach has been established and has shown some success (Jacobson et al., 2005, Gregory et al., 2001, Narfström et al., 2005). However, transferring this approach to human beings will not be easy and a very long period of time will be needed before it can be used in treating patients with RP.

The second approach is to find a neuroprotective treatment which will affect the biochemical pathways. This approach attempts to find an agent that can protect rods and cones against apoptosis (programmed cell death) (Hartong et al., 2006). Several studies have used this approach, and it has been applied to animal models, though its effect and long term efficacy
is unknown (LaVail et al., 1998, Leveillard et al., 2004, Sieving et al., 2006).

A third approach is a pharmacological treatment which uses known medications such as calcium-channel blockers (Frasson et al., 1999). However, three studies which have used this approach in rats did not find any significant benefits (Pawlyk et al., 2002, Bush et al., 2000, Frasson et al., 1999). The pathophysiology of the disease has not been identified (Hamel, 2006) and consequently it is unlikely that a pharmacological cure will be available in the near future.

The transplant of RPE (Lin et al., 1996, Little et al., 1996, Woch et al., 2001), photoreceptors (Berger et al., 2003) and stem cells (Sun et al., 2006, Chiou et al., 2005, Angenieux et al., 2006) has also been explored. However, studies using the transplant approach have so far only been conducted either with rats or in vitro, and results suggest that the application of this approach to humans would face many challenges and take years of development before future introduction as a reliable method.

Finally, devices have been proposed which electrically stimulate the retina, optic nerve, or visual cortex (Chow et al., 2004, Jensen et al., 2005, Brelen et al., 2005, Lee et al., 2000, Gekeler et al., 2007). However, such devices are still under development in order to improve image resolution and have so far only been tested on animals (Hamel, 2006). The few patients who have been tested with these devices have reported seeing flashes of light in response to direct retinal stimulation. However, the success of these on a wider scale is unlikely to be seen for many years.

The studies outlined above indicate that there is a growing research effort to try to treat RP, however an effective approach to treating any form of the disease may not be seen for another
five or even ten years, and saving or restoring vision in all patients could take many decades of research.

In summary, RP is a degenerative retinal disease that develops over a long period of time. Most of the signs, symptoms, and clinical features become obvious by the middle stages of the disease. Unfortunately, there are currently no medical or surgical treatments available to stop its progression or to restore vision, and most of the proposed treatments are unlikely to become available in the near future.

1.4 Orientation and Mobility in Patients with Visual Impairment

Two of the most common limitations that patients with partial sight face are the loss of orientation and impaired mobility (Pelli, 1987b). Mobility can be defined as the physical ability to systematically navigate from one place to another, independently, safely, and comfortably (Dickinson, 1998). Orientation refers to the ability of a person to identify the surroundings sufficiently to be able to identify/know his/her location and to plan an optimal route (Dickinson, 1998). Orientation and mobility (O&M) difficulties affect a patient's independence and this is a crucial element that affects the patient's quality of life (QoL) (Turano et al., 2001, Shinkai et al., 2000, Melzer et al., 2003, Biderman et al., 2002, Cacciatore et al., 2004).

Many studies have found reduced mobility performance in VI patients (Brown et al., 1986, Geruschat et al., 1998, Kuyk et al., 1998, Lovie-Kitchin et al., 1990, Marron and Bailey, 1982, Hassan et al., 2007, Vargas-Martín and Peli, 2006). Pelli (1987b) suggests that a person with VI moves more slowly and less safely than a sighted person. Salive et al. (1994) tested 5,143 visually impaired patients from various disease groups (VA ranged from 6/60 to 6/12
or better) and found that 36% of the participants reported difficulty in performing the mobility task.

Additionally, Szlyk et al. (1997) assessed daily living activities in RP patients by a self-reported outcome questionnaire. They identified mobility as one of six key areas that RP patients find difficult. Turano et al. (2002) report that the five most difficult mobility situations that RP patients are confronted with are: walking at night, moving about in crowded situations, avoiding bumping into low-lying objects, adjusting to lighting changes during the day (outdoor to indoor), and walking in dimly lit indoor areas. These five situations represent the effects of three common clinical features: loss of VF, night blindness, and difficulty in adapting to light changes (Geruschat and Turano, 2002). In addition, patients have trouble seeing obstacles within one metre (arm's length) and may bump into objects and people approaching from the side (Geruschat and Turano, 2002).

When mobility is compromised an increase in the risk of falls would be the obvious consequence (Felson et al., 1989, Lord et al., 1993, Lord and Dayhew, 2001, Biderman et al., 2002, Freeman et al., 2007). In general, the progressive VF constriction may result in either less disability because the patient adopts new coping strategies, or more disability due to loss of confidence and motivation over time (Pelli, 1987b).

1.4.1 Factors that Influence Mobility

Mobility is a complex task that involves visual and non-visual components. The visual components include: VA, CS, VF, eye movements, and visual cues. A number of studies have found that VF and CS are the best predictors of mobility performance. For example, Marron and Bailey (1982) found that log CS accounted for 30% of obstacle contacts on an
indoor mobility course, and Geruschat and colleagues (1998) found that log CS accounted for 30% to 50% of obstacle contacts at a slow walking speed. In general, VF and CS account for 39% to 70% of the variation in mobility performance (Black et al., 1997, Geruschat et al., 1998, Haymes et al., 1996, Kuyk et al., 1998, Marron and Bailey, 1982). The remainder of the variation could be explained by other factors such as illumination, environment colour, rate of movement, personality, risk assessment, prior mobility training, age, and personal knowledge of the environment (Geruschat and Turano, 2002, Lovie-Kitchin et al., 1996).

Lovie-Kitchin and co-workers (1990) examined nine VI patients and nine age-matched normal subjects to determine which areas of the VF are important for mobility. Mobility efficiency was assessed by measuring the time taken to complete, and the number of errors made on, an indoor course. They found that the most important areas for mobility are: firstly, the central 37° radius; and secondly, the right, left and inferior mid-peripheral areas. Lovie-Kitchin and colleagues also conducted a study more recently which aimed to determine the VF size at which a referral for mobility rehabilitation should be performed (Lovie-Kitchin et al., 2010). In this study a larger number of 109 LV patients was recruited. The causes of the VF defect were diverse and participants were divided into two main sub-groups; patients with central field loss (CFL) and patients with mid and peripheral field loss (M and PFL). The findings of this study suggested that, for the full group, mobility performance would be at risk (and probably inadequate) when the VF was 52° in diameter and would be critical (definitely inadequate) when the VF was 15° in diameter. However, when the patients with M and PFL only were taken into account, mobility was considered to be at risk with a smaller VF of 40° diameter. Overall, these findings confirm the difficulties faced by RP patients.

Hassan and colleagues (2007) tested 20 sighted patients on a virtual reality mobility course to
determine the minimum FoV required for efficient mobility. The mobility performance was evaluated by measuring the travel time, time to start walking, and contact errors. Hassan and co-workers found that binocularity did not significantly affect navigation performance. Similarly, the use of chromatic or achromatic images was also not a significant factor affecting navigation performance. The FoV was significantly correlated with the two time measures; the smaller the field the greater the time taken to move off or to complete the course. Finally, the VF required for effective navigation varied according to the level of contrast. Specifically, in a high contrast environment the FoV needed was 10.9° diameter, for mid contrast levels it was 13.4° diameter, and for low contrast levels 32.1° diameter. This conclusion may indicate that RP patients would perhaps require a FoV of 32° diameter to navigate effectively, due to the CS limitations that are typically found in these patients. However, image contrast could be enhanced simply by making changes in the surrounding environment such as painting the edge of steps and curbs with a high contrast colour (e.g. yellow) or by using electronic devices (e.g. head mounted image enhancement device) which could enhance the use of the remaining FoV (Geruschat and Turano, 2002).

The non-visual components that influence mobility performance include age, height, weight, length of legs, and the difficulty of the route (Ralston, 1958). Further, one of the possible determinate of mobility performance is how the patients perceive and assess the risk of injury in a journey. This factor had been suggested by Pelli in his study, where they found that very low levels of vision were adequate to perform the task, and yet many people with much better vision claimed that they could not do it (Pelli, 1987a). This might mean that some VI people are very reluctant to attempt some tasks even when their vision seems adequate; this factor could be referred to as confidence. Additionally, adaptation and training could play a part in
mobility performance. The presence of a general health problem can impact mobility performance and this has been found in several studies, which have identified, for example, strokes (Stoquart et al., 2012) and rheumatoid arthritis (RA) (O'Connell et al., 1998, Clarke, 1993) as contributing factors. Ocular diseases can also cause a reduction in mobility performance and some of the evidence documented in previous studies includes: RP (Turano et al., 1999a, Black et al., 1997), AMD (Hassan, 1999) and glaucoma (Turano et al., 1999b, Friedman et al., 2007). Finally, factors related to the path navigated will also affect mobility performance, e.g. obstacles size, contrast, location and the influence of different lighting conditions or glare (Roentgen et al., 2012, Lovie-Kitchin et al., 1996).

Lovie-Kitchin and co-workers (1996) tested ten RP subjects and nine age matched subjects with normal vision. The main purpose of the study was to investigate the relationship between mobility performance and illumination. The mobility performance was evaluated by measuring the time taken to complete the trial, which was then converted to percentage preferred walking speed (PPWS), and noting the number of errors that were made on a 57.5m indoor course containing 55 obstacles. The subjects were tested twice under high (450 lux) and low (25 lux) illumination. The authors concluded that mobility performance and the number of errors were significantly correlated with the level of illumination (i.e. the lower the illumination level, the slower the patient and the more errors that were made). For example, the number of errors in the RP group was 5.8 ± 6.0 errors with high illumination and 8.8 ± 6.3 errors with low illumination.

Finally, mobility depends also on the amount of attention that a patient gives to the task (Geruschat and Turano, 2002). This attention level is commonly believed to be greater in a person with RP than in someone with normal vision (Geruschat and Turano, 2002). Turano
and co-workers (1998) tested 13 RP and 29 normal subjects in a mobility task. Participants were asked to press a button as soon as they heard a random tone. This approach was intended to show the amount of attention that the patient gave to mobility while considering a secondary task; the slower the reaction to the secondary task, such as the response to the tone, the greater the attention paid to the main task. Turano and colleagues concluded that while walking, the reaction times (RT) of the RP patients were slower than those of the normal subjects. Furthermore, the RT was significantly inversely correlated with log CS and log retinal area (-0.63, -0.64 respectively). In addition, in the same study, the same patients were tested on a more complex course and with the result that the RT for the secondary task was significantly slower than that on the easy route. This result would indicate that the complexity of the environment affects the amount of mental effort that the RP patient has to expend in order to travel in a safe manner.

1.4.2 Rehabilitation Strategies for Orientation and Mobility

The rehabilitation of O&M can be approached using three main strategies. These are: non-optical approach, behavioural approach and optical approach (Geruschat and Turano, 2002). Orientation could be enhanced by the use of electronic devices (e.g. satellite navigation, talking signs) in order to direct and plan a route for RP patients (Geruschat and Turano, 2002).

The non-optical approach to mobility requires the use of obstacle detectors (e.g. sighted guide (SG), guide dog or cane) to gather information about the scene, directly and indirectly, and to signal a change in direction if needed to avoid the obstacle (Geruschat and Turano, 2002, Dickinson, 1998). In the SG technique the patient follows a sighted person half-a-step behind, while holding the sighted person's arm above the elbow. Through this technique any
movement by the SG will be transmitted (through the arm) to the VI patient (Dickinson, 1998). Secondly, a guide dog could help in detecting and avoiding obstacles. However, to be eligible to have a guide dog the patient must be over 16 years of age, healthy enough to take care of the dog and travel on a regular basis. In addition, the patient would need to be trained with the dog in a residential centre for four weeks (Dickinson, 1998). Finally, the cane represents an independent non-optical approach that could be used by most of the patients. There are four different cane types: the symbol cane, white walking stick, long cane, and guide cane (Dickinson, 1998). The cane has several advantages, as it is easy to manage, popular, lightweight, and most importantly allows the detection of low-lying objects (Dickinson, 1998), which is very important in terms of safe navigation (Lovie-Kitchin et al., 1990). In addition, the cane may encourage patients to scan more efficiently, which could improve orientation ability (Brilliant, 1999a, Geruschat and Turano, 2002).

Patients with VI can be trained by an O&M specialist to change some of their habitual behaviour. Two behavioural changes the patient could be trained to adopt are changes in walking speed and visual scanning (Gerushchat and Turano, 2002, Vargas-Martín and Peli, 2006). Slowing the walking speed gives the person adequate time to gather sufficient information about the scene and avoid any obstacles (Gerushchat and Turano, 2002). The person is trained to either slow down or to stand to one side for a while to gather the necessary information. However, difficult situations can arise when dealing with moving objects like people or vehicles (Gerushchat and Turano, 2002). In addition, there are other situations in which the person would not be the controller of his/her speed (e.g. moving with the crowd) and would be unable to slow down or to step to one side, such as in a theatre entrance or train station.
Patients are usually trained (or spontaneously learn) to scan systematically to improve their dynamic FoV (Vargas-Martín and Peli, 2006). Scanning eye movements are commonly assumed to be of greater size and number in patients with TV, in order for them to gather more information than they expect from their available VF. However, Vargas-Martín and Peli (2006) tested five RP patients with a VF of <15° diameter and three normal subjects, and recorded the eye positions relative to the head while the subjects walked for more than 30 minutes. The eye position was recorded by modifying a head mounted system (ISCAN, Burlington, MA) to make it portable. The measure used was the angular eye position dispersion which is the sample horizontal and vertical standard deviations of the angular eye positions. They suggested that the dispersion provides a measure of the range of eye movements during walking. In their results, they reported that the RP patients did not use more scanning eye movements in order to overcome the lost field (Figure 1.3) and they found that the RP patients had a significantly (p < 0.0001) narrower horizontal dispersion of eye positions compared to the normal subjects. The vertical dispersions of the RP and normal subjects were similar (Vargas-Martín and Peli, 2006). The authors suggested that this outcome might be due to the low stimulus rate in the periphery which may not have encouraged the patients to scan. In addition, it may also indicate that these patients have not adopted a good scanning technique. Further, the impact of the TV on saccadic behaviours was investigated (Luo et al., 2008). They reported that saccadic sizes and directions in TV patients were very similar to those of subjects who were normally-sighted (Luo et al., 2008).
Figure 1.3 The results of the angular eye position dispersion are plotted as a box plot.

In Figure 1.3, the "Box plots of angular eye position dispersion in normally sighted subjects (NS) and patients with PFL. Data are segmented by environmental condition: indoors (in), outdoors (out) and overall (total of in and out); and by dispersion component: vertical (Ver.) and horizontal (Hor.). Values for the sample Boxes: medians and quartiles; whiskers: remainder of the sample (unless there are outliers). +, outliers, values >1.5 times the inter-quartile range away from the top or bottom of the box" (Vargas-Martín and Peli, 2006).

Finally, mobility performance could be improved if the FoV was enhanced. Several optical aids have been devised during the last four decades for this purpose. Generally, the idea behind this approach is to magnify the image by <1x or to displace the image towards the functioning area of the VF. The various optical approaches used to enhance the FoV to improve the mobility performance are reviewed in the next chapter.
Chapter Two:
Optical Aids for Visual Field Constriction
2.1 Introduction

Patients with TV usually face major concerns, one of which is the availability of rehabilitation aids to assist them with their awareness of objects outside their VF (Weiss, 1992). Moreover, patients may lose confidence which makes them unable to enjoy efficient and safe independent mobility (Perez and Jose, 2003).

Tunnel vision rehabilitation is challenging for several reasons. Firstly, the VA is often impacted, as patients with RP usually develop posterior sub-capsular cataracts (Dickinson, 1998). Secondly, the causes of this condition, e.g. glaucoma and RP, usually progress slowly. During this period of time patients may learn to cope with their situation and adopt strategies to compensate for their loss such as scanning techniques (Cohen, 1993, Dickinson, 1998). For example, a patient with a static FoV of around 5° could, with a good scanning technique, obtain up to 20° of the dynamic FoV, which would enable awareness of peripheral stimuli and objects in the foveal area (Dickinson, 1998). A poor scanner, however, may maintain the same static VF (Dickinson, 1998). This dynamic FoV of 20° may be just sufficient to enable independent mobility (Gadbaw et al., 1976, Dickinson, 1998). Further, those patients with good scanning ability would not generally notice the field loss and, therefore, would be unlikely to seek professional help until they progressed to a more severe TV (less than 10° extent) (Cohen, 1993, Dickinson, 1998). When seeking help, they usually have high expectations.

Two main approaches are used to enhance the VF in TV patients. The first approach is to use different forms of prism in order to shift the image from the periphery towards the functioning FoV (Figure 2.1). The second is to condense the information from the larger FoV into the smaller remaining VF by using a magnifier with <1x magnification such as a reverse
telescope, amorphic lens or minus lens (Figure 2.1). These optical devices, however, may interfere with adopted behavioural compensatory techniques which can sometimes reduce the dynamic field instead of enhancing it (Cohen, 1993).

A patient's satisfaction with optical aids may be influenced by many factors, such as the aid’s position relative to the optical axis, its power, whether the viewing is binocular or monocular, and the pathological nature of the disorder (Hoppe and Perlin, 1993). In general, every optical aid has advantages and disadvantages.

Figure 2.1 A flow chart of the optical aids available to patients
2.2 The Prism

The main purpose of the prism is to increase awareness of objects located in the periphery, resulting in an increase in visual efficiency. For this reason the prism is used to shift the image from the non-seeing part of the retina to an area closer to the seeing part of the retina. This is achieved by directing the prism base towards the lost field. The effectiveness of the prism is dependent on three factors: the prism power, the prism placement in the spectacle plane, and the object distance (i.e. the further the object is away from the eye, the greater the displacement) (Perlin and Dziadul, 1991, Cohen, 1993). The prism power is the factor responsible for the amount of image displacement on the retina.

The prism can be used to enhance the VF, although it can produce effects which limit its usefulness, such as spatial distortion, chromatic aberration, image degradation and astigmatic error. In addition, the prisms add weight and edge thickness to spectacles (Cohen, 1993, Cotter, 1995). Further, the VA often declines proportionately to the prism power, so that for every five prism diptres, a one line reduction in distance VA is generally seen (Woo et al., 1986). The prism power generally used ranges from 15 to 40 prism diptres. The power of the prism used is dependent upon the patient's need, the size of the FoV, and the patient's ability to adapt to the shifted images. However, some clinicians suggest that treatment should begin with 20 or 25 prism diptres (Dickinson, 1998).

The conventional ophthalmic prism is heavy in weight, increases the spectacle edge thickness, is usually used permanently, and is a full aperture lens (Cohen, 1993, Woo et al., 1986). Because of these characteristics, the Fresnel prism is most commonly used instead. This is a 1mm thick optical polyvinyl chloride (PVC) element with a refractive index of 1.52 (Cheng and Woo, 2001). The Fresnel prism is applied to the back of the spectacle lens.
It consists of a series of tiny prism elements aligned with their bases in the same direction. The thickness of each one is small, which keeps the thickness and weight of the prism to a minimum (Cotter, 1995). The Fresnel prism is inexpensive, lightweight, adjustable, and produces less magnification (Cotter, 1995). However, it does have a number of limitations: there is a high probability that it can fall off, there is noticeable reflection from the facets, it can discolour over time and can cause greater distortion and chromatic aberration in comparison to ophthalmic prisms (Cotter, 1995, Cohen, 1993, Weiss, 1972, Cheng and Woo, 2001, Bailey, 1978b, Onufryk M., 1994, Brilliant, 1999b, Woo et al., 1986).

The flexible Fresnel prism suffers from a lack of optical clarity due to scattered light and low transparency which can lead to a greater decline in resolution and contrast (Cheng and Woo, 2001, Schmiedecke and Jose, 2005) compared to that seen with a conventional ophthalmic prism. For instance, in a study by Cheng et al. (2001), the Fresnel prism caused significant acuity reduction, much greater than the conventional CR39 prism for powers ranging from 5 to 30 prism dioptres for both high and low contrast. Furthermore, the rate of acuity reduction with increasing prism power was greater with the Fresnel prism than with the conventional CR39 prism. Both prism types reduce the VA, but the Fresnel prism’s optical design allows it to reduce the VA and the contrast more.

The placement of the sector prism is a further important consideration when prescribing a prism. The literature shows that there is little agreement regarding the positioning of the prism over the spectacle plane. Ferraro and Jose (1982), Weiss (1972) and Bailey (1978b) recommended placing the prism at 2 to 3mm (or 5°) from the pupil centre in the primary position. Therefore, awareness may be increased by minimising the time taken and size of the eye movement. It has been suggested that the prism is gradually moved towards the periphery...
over time, in response to any observed improvement in scanning ability. Ferraro and Jose (1982) suggest that the use of this approach can result in a larger dynamic field. However, to date there is no objective evidence to support this theoretical approach. Some studies recommend placing the sector prism with a displacement equal to the residual field (Dickinson, 1998). This residual field can be calculated if it is known that every millimetre in the spectacle plane represents 2° of the FoV or eye rotation (Bailey, 1978b). For instance, if the residual field on the lost side was 15°, then the prism would need to be placed 7mm from the pupil centre in the primary position (Gadbaw et al., 1976, Jose and Smith, 1976). Other studies such as Gadbaw et al. (1976) recommend a central 20° FoV (prism placement 10 mm from the centre of the pupil) as a prism-free area to allow the patient to rotate the eyes freely and to encourage scanning.

In general, in TV patients, the sector prisms can be placed on the spectacle lens in several locations around the 360° axis, with the base towards the edge of the lens, to shift the image in all meridians from the non-functioning to the functioning area (Figure 2.2). Sector prisms are commonly Fresnel prisms. The number of prism sectors used is dependent upon the patient's needs and ability to tolerate the displaced image (Brilliant, 1999b).
Figure 2.2 Fresnel prism is fitted over the RE in four directions near the limbus. The prism base is placed towards the edge of the lens, which will shift the image in all meridians from the non-functioning toward an area close to the functioning area (Dickinson, 1998).

The sector prism has been previously used to enhance the VF in patients with TV. Hoppe and Perlin (1993) recruited 22 patients who had VF defects caused by glaucoma, RP, choroideremia and hemianopia. The prism was fitted binocularly and the power selected was 20 Δ. They assessed the efficacy of the Fresnel prism using a level of satisfaction survey. The survey had 35 questions divided into four categories, one of which concerned mobility skills while using the prisms. The study was a retrospective one in which the participants had been prescribed Fresnel prisms previously and a phone interview was conducted. Eighteen out of the 22 patients who were recruited continued wearing the prism: the wearing time varied from 2 to 26 months. However, most of the patients continued to use the long cane in addition to the Fresnel prism. They reported that the satisfaction level for the mobility category was good, ranging from 3 (somewhat satisfied) to 4 (very satisfied).

2.2.1 InWave Prismatic Lens

The InWave is an ophthalmic plastic prismatic lens introduced by Onufryk (1994) to be used in aids for TV patients. The lens consists of a prismatic-free central channel in order not to affect the primary gaze of position; surrounding this channel there are three connected prisms
embedded into the lens where all prisms are apex-centred. The connection of the three prisms improves image clarity. The fitting of this lens is usually binocular. The patient's refraction is incorporated in the spectacle (± 8.00 DS and ± 7.00 DC).

The main advantages of the InWave prismatic lens are that it provides a better optical image than the Fresnel prism, and provides a better cosmetic appearance. However, image jump and an induced paracentral ring scotoma may be experienced by the wearer (Woods et al., 2010a). In addition, the prism power is relatively low (12 Δ horizontally and 8 Δ inferiorly), this means that there is an image shift of 6° which may not provide the enhancement expected by the patient (Woods et al., 2010a). However, the InWave prismatic lens is no longer commercially available and the literature regarding its efficacy is limited (Peli, 2001).

Somani and co-workers (2006) used a simulated in-wave system approach in sixteen patients with RP by using a 20 Δ Fresnel prism binocularly (Figure 2.3). The success of the device was evaluated by assessing vision-related activities of daily living (ADL), and functional field scores (FFS). Somani et al. (2006) claimed that there was an improvement of the questionnaire result by 14% in peripherally related tasks and an 8% improvement in the functional VF score (FFS). The FFS is a score of binocular functional VF (Equation 1), with a total score out of 50.

\[
\text{The FFS} = \frac{\text{the right field score} + \text{the left field score} + 3 \times \text{superimposition score}}{5}
\]

Equation 1
2.2.2 Tri-field prism

Another prismatic lens was introduced by Woods and co-workers in (Woods and Peli, 2002). The Tri-field consists of two prisms where the prism apexes are directed towards each other, and the direction of the shifted image is in the real direction (Figure 2.4). The prism is fitted over one eye while the other eye has a conventional spectacle lens (Woods et al., 2010a). The TV patient maintains the original remaining FoV from the non-prism eye, while the prism lens creates the expansion of the VF. The Tri-field prism is fitted over the poorer eye and is fitted to vertically bisect the pupil (Fig. 2.4,A). When the patient moves his eye to the right, objects in the periphery of the right field are seen and vice versa (Figure 2.5). When the patient maintains primary gaze fixation, the prism junction and all three scenes are visible (Woods et al., 2010a) (Figure 2.5). The images are brought from the periphery (nasal and temporal side) to the central FoV by the poorer eye while the better eye views the visual environment as normal. By this method, three different scenes will be seen in the central view (one from the temporal side, one from the nasal, and the third from the central free prismatic view). It was suggested that the Tri-field could expand the VF without minification or prism scotoma (Peli, 2001) (Figure 2.4 B).
Figure 2.4  A. Tri-field glasses fitted apex to apex over the RE with Fresnel prisms. B. The enhancement of the binocular VF with the Tri-field lens worn on the RE of the subject (Woods and Peli, 2002).
Figure 2.5 Schematic diagram illustrating the visual field expansion of the Tri-field glasses

In Figure 2.5, (a) is the normal view of a patient with TV. In (b) the Tri-field lens is fitted in front of the right eye and the patient is looking to the right while fixating on the coffee pot with the left eye (non-prism eye). The right Tri-field prism has shifted the car into the view of the prism eye. The binocular perception would be of visual confusion, with the pot and the car seen in the same visual direction (the illustration between the eyes). In (c) the wearer is looking to the left and fixating on the fish with the left eye, with the left Tri-field prism shifting the cat into the view. Yet again, visual confusion would be experienced, with the fish and the cat seen in the same visual direction. In (d) the wearer is looking through the junction between the two Tri-field prisms. The view here is more confusing, with part of the prism-eye view coming from each prism part because the gaze shifts across the junction (Woods et al., 2010a).
The Tri-field prism powers are varied according to the extent of the VF loss and the amount of far and near phoria. The prism power should be sufficiently larger than the remaining field diameter (each eye, left and right) to avoid the overlap of the normal view and the prism view (as overlapping could cause diplopia). This approach could eliminate the likelihood of fusion, but could eventually cause visual confusion. Particularly, when the patient wears the Tri-field prism, the eye will move to the phoria position (or the rest position), meaning that the prism power on each side of the eye will be different. Therefore, the Tri-field prism power should be adjusted to overcome the two intermediate phorias, at 3 and 15 feet. Generally, these represent the distance range into which an obstacle would fall (Woods et al., 2010a). Prism power should be greater than the sum of field diameter and phoria, otherwise diplopia will become apparent.

The Tri-field prism has a number of limitations which include: the Tri-field lens affects the central vision and therefore may affect the VA, it causes spatial distortion and visual confusion, and the lens does not shift the image in the lower VF (Woods et al., 2010a). The inferior part of the VF is an important aspect of mobility and collision avoidance (Lovie-Kitchin et al., 1990). Moreover, the prism would not be of any use to patients with one eye or amblyopia and strabismus problems. To overcome visual confusion it was suggested that the two prisms should be tinted with light colours (red and green), an approach based on the vision multiplexing concept. However, the practicality of this approach would need extensive research effort. Multiplexing refers to "the transmission of two or more messages simultaneously over the same communication channel in a way that enables them to be separated and used at the receiving end" (Peli, 2001). In vision science, vision multiplexing is the ability to superimpose two different images from different directions while being able to
differentiate between them (Peli, 2001).

Stringer and colleagues (2004) tested the Tri-field prism in nine TV patients. Adaptation to visual direction, mobility performance and QoL was assessed. Visual adaptation was assessed by a pointing task, mobility performance was assessed by measuring the PPWS in a shopping mall, and the QoL was evaluated using the National Eye Institute Visual Function Questionnaire (NEI-VFQ) and the independent mobility questionnaire (IMQ) (Turano et al., 2002). No change was reported in patient response at the end of the study. The post-test PPWS was significantly less than the pre-test PPWS. In addition, there was no evidence of adaptation to visual direction. A follow-up appointment was made after one month and only one of the nine patients responded positively and continued wearing the prism. This patient reported confronting an average of 4.6 problems per week as a result of the Tri-field prism. However, this might be accounted for by the low wearing time as patients wore the glass for an average of only 0.5 hours per week so they may not have adapted.

Woods et al. (2010a) tested the Tri-field prism in thirteen patients with TV, eight of whom had undergone O&M training. Prism effectiveness was assessed by asking the patients questions related to mobility situations (derived from the IMQ and NEI-VFQ 25) and recording the patient's decision to continue wearing the Tri-field. They had tinted the Tri-field prism with different colours (temporal in red and nasal in green) in the hope that this would assist the patients with identifying the object direction. The study reported that 54% of the patients reported difficulty crossing intersections and 61% reported difficulty in crowds with the Tri-field lens. In addition, none of the patients encountered prismatic image displacement, which means that none of the patients could perceive the direction correctly. Further, the QoL questionnaire showed no statistically significant difference with and without
the visual aid. Moreover, in the follow-up phone call, only three patients were still wearing the prism after one year. Finally, VA remained at the same level during the study. This low success rate may be accounted for by the low average wearing time of 1.2 hours per day. This low success rate may also be attributed to the prism interference with the central vision making adaptation more difficult (Woods et al., 2010a). This low success rate may indicate that the patients could not adapt to the visual confusion associated with the Tri-field prism approach.

In general, the low success rate of these studies indicates that patients encounter difficulty, or no change, when using the Tri-field in mobility tasks especially in crowds. For this reason, more studies need to be undertaken with long term follow up and longer wearing hours to evaluate the effectiveness of this device before any recommendations are made to the patient.

2.3 Minification

In order to enhance the VF, information in the periphery must be transferred to the remaining VF (Cohen and Waiss, 1996). To achieve this either the viewing distance must be increased or the object image should be minified. Viewing distance adjustments are a natural reaction and the VI patients usually adopts this technique. However, the viewing distance cannot always be controlled in all mobility situations. For example, if an impaired pedestrian wants to cross a traffic intersection, it would be impractical to ask him/her to go back several yards before the intersection to check for oncoming cars. Theoretically, optical magnification of <1x is the technique which could be used to help patients in this situation. To gain the required magnification a reverse telescope could be used. There are different forms of reverse telescope, including the reverse Galilean telescope, peep-hole telescope, contact lens reverse telescope, amorphic lens and minus lens.
2.3.1 Reverse Galilean Telescope (or Field Expander)

The optical components of the field expander (FE) are the same as in the Galilean magnifying telescope, with the components arranged in the opposite order (Figure 2.6). The Galilean magnifying telescope cannot be used in reverse as the small diameter of the telescope eyepiece lens would unnecessarily restrict the available FoV.

Holm (1970) proposed a reverse telescope which combined a high power positive lens in a spectacle frame, with a mounted small diameter high minus lens in front of the spectacle. Holm suggested using the reverse telescope as a bioptic telescope. The advantage of using the telescope in a bioptic form was that the resolution did not decrease constantly and distortion could be eliminated (Dickinson, 1998). In this design the patient would benefit from the expanded VF when scanning for something but would not benefit from the telescope while walking. This reverse telescope design has two main limitations in comparison to the cased reverse telescope: the cosmetic appearance and the higher resolution diminution (Drasdo, 1976). Resolution diminution could be accounted for by the full aperture of the ocular lens, due to the +20 DS, fitted in frame before the eye.

Drasdo (1976) also discussed the possibility of using a large field reverse telescope to work as a FE. He suggested that the reverse telescope could be used for constant wear (full field telescope or contact lens telescope) in a bioptic form, or in a hand held form for shorter viewing time. The expected field expansion could be calculated by multiplying the horizontal field diameter by a number equal to the reciprocal of its magnification. For example, for a patient with a 10° VF diameter and a 0.40x magnifier, the expected expansion would be up to 25° (i.e. the expected field = (1/0.4) x horizontal field diameter in degree).
Figure 2.6 Illustration of the optical components of the reverse telescope. This illustration demonstrates the difference in image size while viewing through the reverse Galilean telescope (Daniel et al., 2000).

The main advantages of the reverse telescope are that it provides more object information from the surrounding environment (Dickinson, 1998) and that it increases the depth of field which means that with a small amount of accommodation, patients can obtain a very clear image (Bailey, 1978a, Mehr and Quillman, 1979). Nevertheless, there are some limitations which include: chromatic aberration, curvature aberration (i.e. loss of a clear image at the field edges), difficulty in adjusting to moving objects, and barrel distortion (Bailey, 1978a, Frith, 1979, Holm, 1970, Drasdo, 1976, Weiss, 1992, Dickinson, 1998). In addition, VA would be reduced in proportion to the power of the telescope, due to minification (i.e. the higher the telescope power used, the lower the VA obtained) (Bailey, 1978a, Dickinson, 1998, Weiss, 1992, Kozlowski et al., 1984). Furthermore, this device is not widely commercially available and, therefore, clinicians may not be able to have access to it.

The decline in VA associated with the use of the reverse telescope may limit its use as a constant-wear device unless used at a relatively low power, as suggested by Mehr and
Quillman (1979) in their study of a 0.75x magnifier. Further studies by Drasdo (1976), Drasdo and Murray (1978), and Lowe and Drasdo (1992b), argued that this proportionate decline could be compensated for by an increase in visual efficiency, especially in mobility tasks. However, in two studies (Drasdo and Murray, 1978, Lowe and Drasdo, 1992b), a proportion of the ten patients studied reported difficulty in performing some tasks, particularly those involving movement and crowds. Drasdo and Murray (1978) recommended prescribing the reverse telescope for patients who have a VA of 20/30 or better and/or a VF of less than 15° in order to maximise benefit and efficacy.

Drasdo and Murray (1978) tested the monocular efficacy of the reverse telescope by assessing the time taken to complete visual search tasks. The average VF diameter of their patients ranged from 20° to 35°. The search time with the monocular FE was almost the same as the search time without the device. This result may indicate that the FE is not useful monocularly and may need to be used binocularly. However, Lowe and Drasdo (1992b) assessed the use of the FE binocularly and found that there was no significant difference in the time taken in a search task with or without the device.
2.3.2 Peep-Hole Telescope

Kennedy et al. (1977) suggested an inexpensive commercially available device, the peep-hole telescope, which has traditionally been used in apartment doors. This device can be used monocularly for intermittent tasks and could provide field expansion of between 90° and 140° (Kennedy et al., 1977). However, barrel distortion is greater than that found with a conventional FE. Kennedy et al. (1977) reported that 80% of the subjects studied found that the device disabled them when mobile and when used while walking.

Krefman (1981) tested six subjects (four patients with TV and two normal subjects), comparing the peep-hole approach with other types of reverse telescope using the visual efficiency measure. The visual efficiency method was introduced by Spaeth (1957), who proposed that VI could be assessed using an algorithm. In this algorithm, the VI is measured for the two eyes together using the following equation:

\[
\text{Impairment of visual system} = 3 \times \text{better eye value} + \text{worse eye value} / 4
\]

Equation 2

The better eye values and worse eye values are determined from tables based on a combination of near and distance VA, VF, and ocular motility. Krefman (1981) used this algorithm in his study and compared a 0.21x peep-hole to a 0.45x full field diameter, a 0.40x Selsi hand-held, and a 0.33x bioptic telescope. Krefman concluded that the peephole gave the largest field expansion and the 0.40x Selsi hand-held gave the smallest field increase. Interestingly, visual efficiency did not change significantly with any of the four telescopes in the TV patients, though VA was reduced in the normal subjects.
2.3.3 Contact Lens Reverse Telescope

The contact lens reverse telescope consists of a high plus contact lens combined with a high minus spectacle lens. This design gives the patient the advantage of a better cosmetic appearance (Drasdo and Murray, 1978). Contact lens telescopes provide a larger field expansion than hand-held telescopes (Brilliant and Graf, 1978), but less than the peep-hole system. This is due to the positive lens being closer to the nodal point in the contact lens reverse telescope system than with any other device. Nonetheless, this optical system may be impractical for long term use, as the contact lens will create poor VA for the patient who may take a long time to remove it, and this may discourage some patients (Drasdo and Murray, 1978). In addition, VA for far and near distances would be reduced constantly. To avoid this decline, Enoch (1968) suggested using the reverse contact lens telescope in aphakic patients.

In terms of the efficacy of this device, the literature is limited and mostly restricted to case studies such as the one published by Brilliant and Graf (1978), in which no attempt was made to evaluate the visual aid other than to measure VA and VF. In detail, the patient's left eye (LE) VA was 6/18 (aided and unaided) and the patient had a 5° central field without the device. They used a 0.60x reverse contact lens telescope. The LE VA was reduced to 6/36 and VF was enhanced to 11° as measured by perimetry.

2.3.4 Amorphic Lenses

A new design of the reverse telescope was introduced by Hoeft et al. (1985), but was unfortunately discontinued by the manufacturing company (Design for Vision Inc., Ronkonkoma, NY) in 1998. The main difference between this device and the other reverse telescopes is that the object maintains its original size in the vertical, but the horizontal dimension of the object is minified according to the telescope power (ranging from 0.80x to
As a result, the distance VA was not reduced so greatly. The ability to maintain the vertical size is the result of the high cylindrical powers (at axis 90) used as the ocular and objective lenses (Figure 2.7). Amorphic lenses can provide a FoV of approximately 55° horizontally and 40° vertically (Hoeft et al., 1985). The main disadvantage associated with this device is image distortion due to the asymmetrical magnification. Hoeft and co-workers (1985) reported stable VA, or a decrease of only one line, in 30 of the 39 patients participating in their study.

![Figure 2.7 The optical design of the amorphic system. The cylindrical positive and negative lenses are precisely positioned at axis 90° and are accurately spaced to gain the expected horizontal expansion and maintain the vertical size (Hoeft et al., 1985).](image)

Szlyk et al. (1998b) used the bioptic amorphic lenses in fifteen patients with RP; they were trained for a six month period and their VA, VF, CS, and O&M were assessed. The amorphic lens power selection was based on the highest power that the patient could tolerate while walking, with minimum side effects (the power dispensed ranged from 0.60x to 0.50x). Functional vision was also assessed, and included visual memory, scanning, tracking, recognition, peripheral detection, and mobility. In their result, the VF increased by almost 50% from 28.2 ± 12.8° without the device, to 47.1 ± 16.2° with the device. Interestingly, the
changes in functional vision were notable as most of the visual skills improved by almost 40%. The greatest improvement was seen in mobility skills, which improved by 45% and the lowest improvement was seen in scanning skills, which improved by 25%. In addition, 86% of the patients reported an improvement in their visual skills.

2.3.5 Minus Lenses

A minus lens can be used to create the effect of the reverse telescope when combined with the available amplitude of accommodation. A minus lens provides better central resolution, and minimal distortion and aberration at the periphery in comparison to other reverse telescopes. A minus lens can be held in front of the eye (at about 20 to 30 cm) to work as an objective lens, and the amount of accommodation is considered as the ocular/eyepiece lens (Cohen and Waiss, 1996, Dickinson, 1998). The minification power depends on the minus lens power and its distance from the eye. For example, if a -5 DS was held 20 cm away from the eye, the image of the minus lens would be at its focal point, i.e. the image of the minus lens would be 20 cm away from the lens (1/5 = 20 cm). Consequently, the image would be 40 cm from the eye (Figure 2.8). The patient would then require a +2.50 DS lens to see that image clearly (i.e., 1/0.04 m= 2.50 DS). This also means that the magnification provided would equate to a 0.50x (i.e. 2.50/5 = 0.50x reverse telescope). If the patient accommodation was insufficient, a positive lens could be provided (Dickinson, 1998).
Figure 2.8 Schematic illustration of the optics of a concave lens used to minify the image (Daniel et al., 2000). The small E indicates where the virtual image is formed.

To enable a greater minification effect, the subject needs to move the lens further away from the eye. This technique allows individual subjects to adjust the magnification power according to their needs (Cohen and Waiss, 1996). However, the field expansion experienced is limited by the minus lens diameter and the patient’s residual field diameter. This is because the FoV created by the lens has to be precisely equal to that of the patient's field, otherwise part of the condensed information will fall into the scotomatous area (if the lens is held very near to the eye). If this occurs, the patient will need to move the eye around in order to use the remaining peripheral field to view the condensed area (Dickinson, 1998). The optimum lens distance from the eye can be obtained from a simple formula (Equation 2.3):

\[ s = \frac{d/2}{\tan \alpha/2} \]

Equation 3

Where \( s \) refers to the distance from the eye, \( d \) refers to the lens diameter, and \( \alpha \) refers to residual field diameter (Dickinson, 1998).
The main disadvantage of this device is that it can only be used in stationary tasks; it is impractical for use while walking as it slows the user down, since holding the device while walking affects the attention paid to the task. In addition, as with any minifier, the VA decline is inversely proportional to field expansion (Kozlowski et al., 1984). Moreover, the FoV is limited by the lens diameter (65mm –75 mm was used in Kozlowski et al (1984) study). In order to avoid the central VA decline, Kozlowski and co-workers (1984) suggested making a central hole in the lens to determine object detail once the object of interest was located through the lens periphery. In Kozlowski et al. (1984), two case studies were presented, but objective or subjective responses from the patients were not reported. Overall, the minus lens could be a valuable device for orientation rather than mobility situations.

2.4 Future Field Expander Devices

Two patents for field expanders exist at the time of writing: the poly-powered optical system (Grech, 2001) and the ophthalmic VF extension device (Paul, 2003). However, as they are still in their theoretical form and have not been applied in any clinical trial, their potential efficacy for TV patients cannot be determined yet. Although this review covers only optical systems, there are a number of electronic devices that have also been proposed to help patients navigate a clear path. Such devices include the head mounted field expander system (Apfelbaum et al., 2007), and the portable obstacle detector system (Molton et al., 1998). However, these devices are still undergoing preliminary laboratory testing and require more time before their effectiveness can be assessed in patients. Early indicators suggest that as these are electronic devices, the cost may be prohibitive.
2.5 Summary and Discussion

Some of the optical aids presented here are theoretical, while others are commercially available at the present time. Some of these devices are used for stationary (or sighting) tasks, such as the minus lens and peep-hole, and some can be used while moving, such as the prism and the reverse telescope. The theoretical approaches presented here need to be applied to real TV patients to determine the potential benefits and disadvantages. Interestingly, none of the papers reviewed here were randomized controlled studies; yet were cross-sectional studies. This could be due to the rare occurrence of the targeted conditions which commonly cause TV, such as RP, Usher syndrome and choroideremia. This would lead to difficulty in recruiting large numbers of TV participants for a study.

Commonly used treatment approaches are the prism, which represents the image shift approach, and the reverse telescope, which represents the minification approach. These aids enhance the patient's field, although much of the evidence regarding the effectiveness of these devices is anecdotal and depends on subjective ratings, or visual function measures such as VF. Furthermore, the studies that have been carried out to evaluate these aids in specific tasks, particularly mobility, are very limited. This would be important to know, because any improvement in mobility would be likely to improve the patient's QoL.

The limited literature directed towards evaluation of the effectiveness of these aids for TV patients is reviewed here. Some of these studies did not systematically test and monitor device success, but were limited to case studies such as those by Brilliant and Graf (1978) and Kozlowski et al. (1984). Other investigators evaluated the optical aids according to the patient's VF (or a measure derived from it, such as the FFS) and/or patient response and feedback or both (Somani et al., 2006, Kennedy et al., 1977, Krefman, 1981, Frith, 1979,
Brilliant and Graf, 1978, Hoeft et al., 1985, Hoppe and Perlin, 1993). These are the key measures used to evaluate many optical aids, but when used alone do not provide insight about their effect on the patient's functional performance. With any of the optical aids mentioned above, the VF will be enhanced and this improvement can be easily measured. However, this does not necessarily mean that the patient will be able to benefit from this increased VF in everyday activities such as mobility. In addition, patient feedback is subjective and, therefore, studies may be more liable to poor reproducibility over time.

Mehr and Quillman (1979) and Szlyk et al. (1998b) assessed the patient's mobility performance by using an O&M specialist. This method would provide indications of how the patient would perform in real life. However, coding the patient's mobility might be considered to be un-reproducible and not rigorous (i.e. two O&M specialists may code patient performance differently). Further, professional O&M instructors would not be available in every clinic where optical aids are being prescribed on an irregular basis.

We are aware of only three studies to date that have used objective methods to assess optical aids for TV patients: Drasdo and Murray (1978), Lowe and Drasdo (1992b) and Stringer and colleagues (2004). Drasdo and Murray (1978) and Lowe and Drasdo (1992b) tested the reverse telescope in TV patients. They assessed the optical aid efficacy using a visual search task. Their search task suffered from several limitations and will be discussed in detail in Section 8.1.

Stringer et al. (2004) tested the Tri-field in TV patients, assessing prism efficacy using adaptation to visual direction, mobility performance and QoL. Visual adaptation was assessed by a pointing task and mobility performance was tested by measuring the PPWS in a
shopping mall. We believe it is vital to investigate whether there are other skills, particularly those based on a visual search paradigm, that could be assessed objectively to obtain a better understanding of optical aid efficacy. Our proposed study aims to find an accurate, reproducible and valid method to assess optical aid effectiveness for TV patients.
Chapter Three: The Evaluation of Mobility
3.1 Introduction

The term ‘orientation’ has been defined as the situation where a person identifies his exact location from the information provided by the surrounding environment (Dickinson, 1998). The word ‘mobility’ is used to refer to the ability to travel from one place to another safely and independently (Dickinson, 1998). The challenges facing researchers when dealing with O&M is that there are no universally accepted standards against which to measure performance, which is difficult to quantify (Marron and Bailey, 1982). Orientation was not measured in many of the studies reviewed, possibly due to the nature of the task itself. For example, any of the participants in most of these studies knew their exact location already and so there would have been some difficulty in testing this skill. However, there are two suggested methods for the quantification of functional mobility performance: the use of a mobility course and investigation of the visual search ability.

3.2 The Mobility Course

In some studies mobility has been evaluated using qualitative methods. For example, Szlyk et al. (1998b) graded mobility by assessing the patient's ability to cross intersections, navigate crowded public places and negotiate stairs. In addition, they graded orientation according to the ability of the subject to find particular building entrances, to find particular items on a crowded shelf, and to locate a small shop. The patient's ability was evaluated by an O&M specialist who classified the performance into five grades: 1 (unable to perform), 2 (extreme difficulty), 3 (moderate difficulty), 4 (mild difficulty), and 5 (no difficulty). However, this method may be more prone to bias.

There are three objective approaches which have been proposed in the literature to evaluate
mobility performance: the indoor mobility course, outdoor mobility course, and virtual reality environment. The first two methods have common features in their design, but the VRE method appears to be different in every study.

3.2.1 Mobility Scoring Techniques

Mobility can be quantified by measuring the efficiency and safety of the subject (Armstrong, 1975). Efficiency can be defined as the ability to finish the route as quickly and smoothly as possible, and by the straightest path (Armstrong, 1975). This can be quantified by measuring the time taken to perform the task. The safety of the subject can be defined as the ability to travel without causing physical damage to the subject or to other pedestrians (Armstrong, 1975). This can be quantified by measuring the errors made while performing the task, e.g. bumps, stumbles, high stepping, missed curbs, loss of balance, obstacle contact, stopping, and examiner intervention, or by visual detection distance (VDD) i.e. the distance between the subject and the obstacle at the point when the subject first notices the obstacle. Safety and efficiency are related to each other, meaning that the outcome of one factor would be likely to affect the outcome of the other. For example, if a pedestrian is over-careful while walking in order to avoid collisions, an effect of reduced walking speed would be observed.

Travel time can be defined as the time needed to complete a task. This technique was used in several of the studies reviewed and has been applied to both VI patients and control subjects (Brown et al., 1986, Geruschat et al., 1998, Kuyk et al., 1998, Turano et al., 1999b, Turano et al., 2002, West et al., 2002, Wilcox and Burdett, 1989). However, people usually adopt a walking speed which is suitable for them and which is influenced by age, height, weight, length of legs, and the difficulty of the route (Ralston, 1958). Therefore, it may not be appropriate to compare travel time for two participants engaged in the same task, even if they
have the same visual abnormality. Clark-Carter et al. (1986) introduced the concept of preferred walking speed (PWS) as the time taken to walk an unobstructed path at a normal comfortable speed (i.e. normal pace) under normal illumination.

The PWS is generally believed to be the speed that the visually impaired patient would walk at if his/her vision was restored (Soong et al., 2004). The PWS could be then converted to the PPWS by dividing the obstructed route walking speed (for the real course) by the PWS. For example, if the PWS of a subject was 2 m/s and the walking speed in the obstructed route were 1 m/s, then the PPWS for that particular subject would be 50% (i.e. 1/2*100). The advantage of the PPWS is that it "allows subjects to act as their own controls, normalizing data for differences in age, height and physical fitness" (Soong et al., 2001). This method has been used in many research studies (Soong et al., 2001, Soong et al., 2004, Black et al., 1997, Leat and Lovie-Kitchin, 2006, Leat and Lovie-Kitchin, 2008, Jones and Troscianko, 2006, Patel et al., 2006, Lovie-Kitchin et al., 1996, Haymes et al., 1996). The PPWS factor could be considered as a valid inter-subject comparison and Clark-Carter and colleagues (1986) suggest that it may allow smaller subject sample sizes to be studied.

Two techniques have been used to determine the PWS. The first method is the SG technique, in which the patient is instructed to walk at his/her normal pace while holding a sighted person in front of him/her (Clark-Carter et al., 1986, Haymes et al., 1996). The advantage of this technique is that it avoids putting the subject under stress (Beggs, 1991). The second technique is the non-sighted guide technique (NSG) in which the subject is instructed to walk unaided along an unobstructed and unfamiliar path at his/her normal pace (Black et al., 1997, Soong et al., 2001, Hassan et al., 2002). The advantage of the NSG technique is that it removes potential external influences (positive and negative) on the subject's performance:
for example, the investigator may hinder the subject causing them to walk slower than normal.

Soong and colleagues (2000) compared the two techniques (SG and NSG) in 14 VI patients, and found that there was no significant difference between them. Further, Soong et al. (2004) tested the two techniques again, but included a third technique (the string technique) to determine the PWS in a wider group of subjects (in terms of vision disability and age, where 40 patients, with central and peripheral field loss, were recruited). The string technique was a string attached to two poles, one at each end of the route, and a cardboard tube threaded onto the string. The patient is instructed to hold the cardboard lightly and to walk from one end to the other at his/her normal pace. The rationale of this method is the elimination of any uncertainty that the subject may experience. They did not find any statistically significant difference between the three methods.

Mobility safety can be quantified by measuring the number of incidents or errors, and/or the VDD. The number of mobility errors has been used in most studies that investigate the correlation between mobility and VI (Brown et al., 1986, Black et al., 1997, Lovie-Kitchin et al., 1996, Geruschat et al., 1998, Kuyk et al., 1998, Soong et al., 2001, Turano et al., 1999b, Leat and Lovie-Kitchin, 2006, Leat and Lovie-Kitchin, 2008, Wilcox and Burdett, 1989, Velikay-Parel et al., 2007, Turano et al., 2004). Examples of these incidents include: bumps, stumbles, neglecting to detect stairs, deviation from the path, high stepping, missed curbs, loss of balance, obstacle contact, stopping and examiner intervention (Black et al., 1997, Geruschat et al., 1998, Jones and Trosclair, 2006). Each of these errors is counted as an incident and would be analysed as a single variable (i.e. the number of errors). However, the majority of studies agreed that the error frequency is usually low (Black et al., 1997, Kuyk et
The second mobility safety measurement is VDD which was introduced by Rich et al. (2003). This was proposed as a second measure of safety and rehabilitation success due to the low frequency of obstacle contact errors. To obtain VDD measurements, patients were instructed to notify the experimenter verbally if they detected an obstacle in their path. The distance from the obstacle when the patient first notified the examiner was recorded. The greater the distance from the obstacle, the higher the safety level. This technique was used in studies by Leat and colleagues (2006, 2008) (Figure 3.1) and Rich et al. (2003), and has shown good validity (i.e. strongly statistically associated with most vision measures) and good correlation with the number of incidents (Leat and Lovie-Kitchin, 2006). This technique could provide a reliable baseline measure for comparison.

Figure 3.1 A stepladder placed 28 metres from the start point of the mobility course to test the VDD measure (Leat and Lovie-Kitchin, 2006)
3.2.2 Indoor Mobility Course

An indoor mobility course could be designed and constructed to evaluate mobility performance in a safe and controlled environment. Many studies have designed indoor mobility courses which have varied in terms of their pathway lengths and obstacle densities (Table 3.1). The illumination, safety, obstacle density, absence and presence of people, and the course difficulty is strictly controlled in this method (Leat and Lovie-Kitchin, 2006). However, to set up the experiment in a large laboratory for a single study may not be good use of resources. However, if the course has to be dismantled and then re-installed for every participant, it could be time consuming especially in a lengthy course (Leat and Lovie-Kitchin, 2006).

Each of the indoor course studies have different designs ranging from easy to complex, i.e. from very short to very lengthy courses, and the obstacles from none to 100 obstacles. Brown and co-workers (1986) constructed a mobility course consisting of four paths: square, triangular, normal slalom (with poles in a straight line 1.50 m apart for 6.1 m), and random slalom (with three internal poles, displaced by 15.2 cm and spread out in random directions along the pathway). The experiment took place in an indoor room (6.1 x 9.1 m). The length of the square and triangular path was 10.80 m and both slalom routes were 17.68 m. In order to evaluate the patient's performance, the total time required to accomplish the task and average speed were recorded. Wilcox and colleagues (1989) designed an indoor course which included steps, a ramp, two corners and a platform in between two white border lines. The performance was scored according to the patient's travel time and the number of errors. Finally, West and co-workers (2002) measured mobility performance by timing four simple skills: four metres of walking, negotiating a step upward, negotiating a step downward, and
getting up from a chair and moving away.

In these three studies, the mobility course was simple and did not include a wide range of obstacles of differing sizes and contrasts. Therefore, due to this design it seems that there were insufficient errors to show the variation between the individual participants (Leat and Lovie-Kitchin, 2006). Brown and colleagues (1986) did not find any variation between control subjects and AMD patients. The average speed and the total time required to complete the task was not significantly different between subjects; the average speed in the regular slalom course was 1.75 feet/sec for the ten patients with AMD and 2.25 feet/sec for the eight control subjects). Wilcox and Burdett (1989) also failed to find any difference in performance between control subjects and AMD patients. The travel time was 20.5 seconds for the eleven control subjects and 26.4 seconds for the ten AMD subjects, which is not statistically significant after adjusting for age (Wilcox and Burdett, 1989). Further, the number of errors during the course was 0.46 in controls and 1.4 for AMD subjects, which was not statistically significant either by the use of t-tests or Mann-Whitney U tests (Wilcox and Burdett, 1989). The results from Brown et al. (1986) and Wilcox et al. (1989) may contradict the common assumption that patients have poorer mobility performance than control subjects (Geruschat et al., 1998). It would appear that these courses were not challenging enough to differentiate between different levels of performance. Additionally, it could be argued that these courses did not represent the complexity of the real world and are therefore not very useful in the evaluation of the effectiveness of visual aids in mobility performance.

Geruschat et al. (1998) designed two courses in an indoor setting (Figure 3.2). The first was a simple mobility course and was chosen to allow all the subjects to participate in the
experiment despite their level of VI. The second was more complex, containing more obstacles, varied illumination along the pathway, and more pedestrians. In fact, the more complex course was similar to the outdoor course design (discussed later). The first controlled mobility course was 49m long with obstacles such as paper cups hanging from the roof and floor mats. During the course there were few or no pedestrians. The second course was the main corridor of a hospital (444m long). The corridor was crowded with pedestrians and contained a reception desk, elevator, patient waiting area, shops, pharmacy and steps.

Figure 3.2 Schematic diagram of mobility courses used by Geruschat et al. (1998)

In Figure 3.2, the simple course (a) was 49m long, paper cups were hanging from the roof (denoted as circles) and floor mats (denoted as squares). The complex course (b) was 444m, which involved steps (denoted as 1), a glass door to walk through (2), and an escalator whose location needed to be identified (3).

In the study by Geruschat et al. (1998), the walking speed and mobility incidents in the RP subjects were almost equal in both courses under normal illumination. The mean walking speed was 1.12 m/s, with the 18 patients who scored no incidents in the simple course, and 1.16 m/s, with the 19 patients who scored no incidents in the complex course. However, no
attempt was made to compare the mobility performance of the RP subjects in both courses. Finding no marked difference between the two courses could be accounted for by the layout of the obstacles, as they were not very dense and perhaps did not challenge the patients sufficiently to be able to differentiate between good and poor performers. Using a lengthy mobility course might not be sufficient to simulate the complexity of the real world environment.

Lovie-Kitchin et al. (1996), Black et al. (1997), Hassan et al. (1999, 2002), Soong et al. (2001), Turano et al. (2002), and Leat et al. (2006, 2008) each designed a medium difficulty course, in comparison to the previous studies. The pathway lengths ranged from 29m to 79m and the obstacle densities were between 1 and 2 obstacles per metre. These obstacles were randomly distributed. Generally, the patient's performance on the indoor courses was found to be related to several visual function measures (i.e. VA, CS, VF) (Marron and Bailey, 1982, Brown et al., 1986, Turano et al., 1999a, Turano et al., 1999b, Black et al., 1997), yet a relationship was found even when simple tasks, such as going up and down the stairs, or the time taken to stand from sitting, were conducted and these simple measures were used by West and colleagues (2002).

In conclusion, there is little agreement regarding specific standards or design for indoor mobility courses. However, from the previous studies and experiences, some of the characteristics of the courses can be summarized. Firstly, the mobility course should be long enough to increase the chances of the participant making errors (at least one incident); errors are a vital measure to assess travel safety. In addition, this would enable the measurement of the performance differences between the different participants (Leat and Lovie-Kitchin, 2006). However, the course should not be too long, no more than 100m, as this may lead to a
loss of control over the experiment due to extended travel time and errors might be missed. Furthermore, the course should be well controlled in terms of pedestrian presence or absence because this may lead to obstacle variation at different times and between subjects. Pedestrian presence may lead to loss of control over the course complexity, as was found in the study by Turano et al. (1999a), in which the course was held in an indoor hallway used by the public. In addition, this factor could affect the repeatability of the task. The course should be rich in obstacles in order to provide a visually complex course which adequately assesses mobility skills and at the same time gives the opportunity for errors to occur (Leat and Lovie-Kitchin, 2006). Obstacle density should be at least one obstacle per metre. This obstacle density might not represent the real world environment, but would enable us to challenge the patients in order to differentiate between levels of performance. Thirdly, the obstacles themselves should be of low and high contrast relative to the background, and of various sizes and heights, in order to be related to the visual function scores and to simulate different types of obstacles that are found in the surrounding environment. In laying out the obstacles, positioning them to the sides should be avoided, as patients could easily walk down the middle of the corridor without really scanning and/or making efforts to avoid contacting the obstacles. For example, Soong et al. used a large number of obstacles (100), yet only a few of them were placed in the middle of the course (Figure 3.3) (Soong et al., 2001), which could be the reason why the patients had relatively low error scores. Finally, obstacles should be made from light materials such as foam, soft cardboard, paper, and polystyrene, as they were in most of the studies (Soong et al., 2001). These materials have the common advantage that they are soft and will not harm the subject negotiating the course. In addition, these materials can easily be shaped to different sizes and heights and are easy to set up and dismantle.
In Figure 3.3, Level 1 refers to 0 to 13 cm (ground to ankle); Level 2, 14 to 49 cm (ankle to knee); Level three, 50 to 99 cm (knee to waist); Level 4, 100 to 150 cm (waist to shoulder); Level 5, 151 cm and above (shoulder and above). High refers to high-luminance obstacles and low refers to low luminance obstacles.
Table 3.1 Indoor Mobility course studies that have been reviewed

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Population Characteristics</th>
<th>Pathway Characteristics</th>
<th>Obstacle Characteristics</th>
<th>Scoring Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marron and Bailey</td>
<td>1982</td>
<td>19 patients with LV</td>
<td>➢ 12.2m x 2.4m ➢ hallway corridor ➢ there are small difference in CS between wall and floor</td>
<td>➢ paper cylinder ➢ diameter from 0.50 to 15cm ➢ height from 25 to 125cm ➢ distributed in slalom shape</td>
<td>Scaled according to the time taken to adjust after contacting obstacle</td>
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<td>Course B.</td>
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<tr>
<td>Brown et al.</td>
<td>1986</td>
<td>18 Subjects, 10 ARMD patients and 8 controls</td>
<td>➢ 4 paths (triangular, square, regular slalom, and random slalom) ➢ inside a lab (6.10m x 9.1m) ➢ triangular and square = 10.8 m ➢ regular slalom, and random slalom = 17.68m ➢ subjects were tested under three types of illumination (0.03, 0.3, and 71 cd/m²)</td>
<td>➢ Unobstructed in triangular and square routes. ➢ Normal slalom (poles were in a straight line and 1.50m apart for 6.1m) ➢ Random slalom (the three internal poles were displaced by 15.2 cm in and spread in random directions along the pathway)</td>
<td>Scores were derived from a computer system: 1- Average of speed 2- Average deviation from average speed. 3- Root mean square deviation from average speed. 4- Average deviation from ideal path 5- Average acceleration 6- Number, position, and duration of stop. 7- Latency to begin walking after cue to start was given.</td>
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<td>Black et al.</td>
<td>1997</td>
<td>10 patients with RP and 9 age matched control</td>
<td>➢ 57.50m long through three rooms. ➢ Glare was tested in room 2 with 200 watt spotlight position 1.2 m height. ➢ Step and ramp was included</td>
<td>➢ 55 obstacles made from foam rubber, cardboard or polystyrene. ➢ Obstacles vary in size and CS. ➢ Distributed randomly (from the roof, at the sides, on the mod of pathway)</td>
<td>1- PPWS 2- Number of errors</td>
</tr>
<tr>
<td>Study</td>
<td>Year</td>
<td>Population Characteristics</td>
<td>Pathway Characteristics</td>
<td>Obstacle Characteristics</td>
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<tr>
<td>Lovie-Kitchin et al.</td>
<td>1997</td>
<td>10 patients with RP and age matched control</td>
<td>➢ 57.50m long.</td>
<td>➢ 55 obstacles</td>
<td>1-Number of errors 3- PPWS</td>
</tr>
<tr>
<td>Geruschat et al.</td>
<td>1998</td>
<td>25 patients with RP and 24 control subjects</td>
<td>➢ Path one: 49m hallway</td>
<td>➢ Path 1: paper cups hanging from the roof and floor mats</td>
<td>1-Walking speed 2-Number of errors</td>
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<td></td>
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<td>➢ Two illumination levels: normal illumination (8.6 to 47.3 metre candle), and low illumination (reduced by 11% from the normal setting)</td>
<td>➢ Path 2: up and down stairs  ➢ Negotiating automatic door  ➢ Identification the location of an escalator</td>
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<td></td>
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<td>➢ Path two: 444 m busy hospital corridor</td>
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<td></td>
<td>➢ Illumination ranged from 23.7 to 274.4 metre candle</td>
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<td>Kuyk et al. Part 1</td>
<td>1998</td>
<td>87 patients with LV</td>
<td>➢ Part 1:150 metre extended for two level</td>
<td>➢ Part 1: Six doors which the patients have to open.</td>
<td>1-Travel time 2-Number of errors</td>
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<td></td>
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<td>➢ Two illumination level (62 cd/m2 for photopic and 2.5 cd/m2 for mesopic induced by sunshades).</td>
<td>➢ Along the wall obstacles include a copy machine, coffee table, cabinet, pedestrian, housekeeping carts.</td>
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<tr>
<td>Turano et al.</td>
<td>1999 b</td>
<td>47 patients with glaucoma and 47 control subjects</td>
<td>➢ Indoor hallway</td>
<td>➢ Patient Waiting area contains chairs and tables</td>
<td>1-Walking speed 2-Number of errors</td>
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<td></td>
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<td>➢ Path one 29m long with no obstacle.</td>
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<td>➢ Median number of people during the test was one</td>
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<td></td>
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<td>➢ Illumination range from 74.30 to 245.4 Lux.</td>
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<td>➢ Path two 29m long with obstacle</td>
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<td>➢ Median number of people during the test was four</td>
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<td>➢ Four right angle turn</td>
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<td></td>
<td></td>
<td></td>
<td>➢ Illumination range from 88.3 to 199.1</td>
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<td>Study</td>
<td>Year</td>
<td>Population Characteristics</td>
<td>Pathway Characteristics</td>
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</tbody>
</table>
| Soong et al.  | 2001 | 37 patients with LV         | ➢ 78.9m Two linked laboratories  
➢ Glare was tested by 60 watt spotlight.  
➢ Normal illumination throughout the course (425 Lux) | ➢ 100 obstacles, various heights and sizes  
➢ Low and high CS  
➢ Soft card, foam polystyrene and paper  
➢ Hanging and standing obstacles  
➢ Obstacles randomly distributed and sub-scaled to 5 levels: ground to ankle, ankle to knee, knee to waist, waist to shoulder, shoulder and above. | 1-Number of errors  
2- PPWS |
| Hassan et al. | 2002 | 21 subjects, 11 patients with ARMD and 10 aged matched control subjects | ➢ 78.9m Two linked laboratory  
➢ Glare was tested by 60 watt spotlight.  
➢ Normal illumination throughout the course (425 Lux) | ➢ 100 obstacles, various heights and sizes  
➢ Low and high CS  
➢ Soft cardboard, foam polystyrene and paper  
➢ Hanging and standing obstacles randomly distributed.  
➢ Obstacles sub-scaled to 5 levels: ground to ankle, ankle-knee, knee-waist, waist-shoulder, shoulder and above. | 1- PPWS  
2- Number of errors |
| Turano et al. | 2002 | 83 patients with glaucoma   | ➢ Path two 29m long with obstacle  
➢ Median number of people during the test was four  
➢ Four right angle turn  
➢ Illumination range from 88.3 to 199.1 | ➢ Patient Waiting area contains chairs and table | 1-Walking speed  
2- Number of errors |
| West et al.   | 2002 | 2520 Elderly subjects      | ➢ 4 metre walk  
➢ Stair ascent  
➢ Get up and go from a chair  
➢ Normal illum. (400 to 600 Lux) | ➢ No obstacles | 1- Walking speed |
<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Population Characteristics</th>
<th>Pathway Characteristics</th>
<th>Obstacle Characteristics</th>
<th>Scoring Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turano et al.</td>
<td>2004</td>
<td>1504 Elderly subjects</td>
<td>16.4m long</td>
<td>hanging plants, waste baskets, and wooden rulers</td>
<td>1- walking speed</td>
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<td></td>
<td></td>
<td></td>
<td>The course was travelled twice</td>
<td></td>
<td>2- Number of errors</td>
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<tr>
<td>Leat and Lovie-Kitchin</td>
<td>2006</td>
<td>35 patients with LV</td>
<td>39 metre long 4 parts</td>
<td>Pot plants</td>
<td>1- PPWS</td>
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<tr>
<td></td>
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<td></td>
<td>4 obstacles in each part with different height.</td>
<td>Wooden ruler to simulate steps</td>
<td>2- Number of errors</td>
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<td></td>
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<td></td>
<td>Low contrast obstacle</td>
<td>Ramp</td>
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<td></td>
<td>Change contrast of pavement.</td>
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<tr>
<td>Patel et al.</td>
<td>2006</td>
<td>1504 Elderly subjects</td>
<td>16.4m long</td>
<td>发光植物,废物箱,木制尺子</td>
<td>1- PPWS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The course was travelled twice</td>
<td></td>
<td>2- Number of errors</td>
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<tr>
<td>Velikay-Parel et al.</td>
<td>2007</td>
<td>10 patients with RP</td>
<td>4 indoor paths 11.2 metre length each path was repeated 4 times.</td>
<td>In each path 11 obstacles were randomly distributed.</td>
<td>1- walking speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mobile white screen of 1.40 width to simulate maze pattern</td>
<td>2 obstacles were at knee-level (30 cm), 2 at hip-level (90 cm), 3 at shoulder level, and 3 at eye-level (130 cm and 150 cm).</td>
<td>2- Number of errors</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal illumination (800 Lux)</td>
<td>A wooden white step.</td>
<td></td>
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<tr>
<td>Leat and Lovie-Kitchin</td>
<td>2008</td>
<td>35 patients with LV</td>
<td>39 metre long 4 parts</td>
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<td></td>
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3.2.3 Outdoor Mobility Course

An outdoor mobility course can also be used to assess the patients' functional performance. Participants can be evaluated and graded according to their ability to perform visual skills tasks such as finding a particular building or sign in the street, crossing an intersection, navigating and travelling safely from one place to another, and finding a bus stop or walking in a busy public place (qualitative technique) (Szlyk et al., 1998b) (Table 3.2). Some of these skills are orientation skills which can be assessed by this method, whereas this may not be possible in other approaches. The mobility assessment could be performed by using the same measures that are used in the indoor mobility courses, i.e. travel time, walking speed, number of errors, PWS, PPWS or by recording the time taken to adjust after contacting an obstacle (Haymes et al., 1996, Kuyk et al., 1998, Marron and Bailey, 1982) (Table 3.2).

The outdoor mobility course may represent the natural environment in which the participant lives, but still has some important drawbacks. The first drawback is the lack of control over obstacles in the surrounding environment and the time required to conduct the test in order to maintain consistency of the experiment. In other words, obstacles may vary in size and contrast from one subject to another. Consequently, this could lead to poor control of the course itself and poor reproducibility. Moreover, the patients would need to deal with obstacles such as other people ('extra moving' obstacles) and investigators cannot control these obstacles (Leat and Lovie-Kitchin, 2006). Additionally, these obstacles may lead to physical injuries that may affect participant safety. Finally, the illumination of this course would be uncontrollable as it is dependent on the location, time, and weather. This, again, would make repeatability more difficult.
# Table 3.2 Outdoor mobility course studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Population Characteristics</th>
<th>Pathway Characteristics</th>
<th>Obstacle Characteristics</th>
<th>Scoring Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marron and Bailey Course A.</td>
<td>1982</td>
<td>19 LV patients</td>
<td>- Triangular city blocks&lt;br&gt;- To ensure the illumination level, subjects were tested in the early afternoon</td>
<td>- Various obstacle with different contrast such as foot path (low contrast) or mail box (high contrast)</td>
<td>Scaled according to the time taken to adjust after contacting obstacle</td>
</tr>
<tr>
<td>Haymes et al.</td>
<td>1996</td>
<td>18 RP patients</td>
<td>- Path 1: 238m quiet residential area, unobstructed path.&lt;br&gt;- Path 2: 202m small business street, with medium obstacle density.&lt;br&gt;- Path 3: 254m indoor busy mall, high obstacle density.&lt;br&gt;- All the tasks complete in one session at the same time of the day.</td>
<td>Path 2: pedestrian, rubbish bins signs, seats.&lt;br&gt;Path 3: pedestrian, rubbish bins signs, seats, plants, escalators, major displays, sculptures.</td>
<td>1- PPWS 2- Number of errors</td>
</tr>
<tr>
<td>Szlyk et al.</td>
<td>1998</td>
<td>15 subjects, RP choroideremia, or Usher’s syndrome type 2</td>
<td>- Several orientation and mobility tasks</td>
<td>N.A</td>
<td>Qualitative technique</td>
</tr>
<tr>
<td>Kuyk et al. Part 2</td>
<td>1998</td>
<td>66 patients with LV</td>
<td>- The first route was 333m and the second route was 400m. Residential / small business street.&lt;br&gt;- Illumination high (2250 cd/m² on sunny day and 1140 cd/m² on cloudy day) and low illumination (7 cd/m²) induced by sunshade.</td>
<td>Broken pavement, pedestrian, garden hose, dogs, protruding branches, mail box, telephone pole, curbs, trash bins, parked cars.</td>
<td>1-Travel time 2-Number of errors</td>
</tr>
</tbody>
</table>
3.2.4 Virtual Reality Environment

The virtual reality environment (VRE) is a simulated mobility course where the participants can be tested in a controlled laboratory setting. In the VRE course every study has its own design for assessing mobility performance. Some of these measures are not limited to VRE and have been applied in previously mentioned methods such as the travel time and the VDD. However, some of the measures are sophisticated and would be difficult to apply in other studies without using the same course design and using the VR simulation.

The first approach is to simulate the physical act of mobility by setting the subject in front of a rear projector with a treadmill facing the rear projector on which they can walk. An example of such a mobility course is that used in the study by Apfelbaum and co-workers (2007). The course was based on an indoor mall video and used the SENSE 8 World toolkit software package (this has now been discontinued, but was originally available from Inition, London, United Kingdom). An alternative package is the world toolkit API software (Luo et al., 2007), which is a custom software designed to run on an Evans and Sutherland SimFusion 4000q graphics workstation. This software allows the developer to build real-time 3D simulation "virtual world" applications that can be run on a desktop computer. Participants would then be asked to walk through the mobility course and to decide whether to go right or left in response to the different trajectories (or obstacles) presented. The time and distance before changing direction and following detection of obstacles were measured (Apfelbaum et al., 2007).

Luo et al. (2007) modified the VR indoor-mall course to test collision judgment in their head-mounted VF expander device. They added various real size (2m high and 0.70m wide) obstacles at five metres away from the subject where the obstacle was visible for one second. The offset positioning of the obstacles was between 20cm and 120cm on each side of the
route. Each eye was tested separately and the subjects were instructed to decide whether they would have made contact with the obstacle or not, even if they were uncertain. The results were in the form of yes/no answers and were given values (yes=1, n=0). The mean result of each eye represented perceived safe passing distance (PSPD). The standard deviation of the PSPD represented decision certainty. Another measurement that was extracted from this measure is the collision envelope (CE). This was obtained by summing up the PSPD on both eyes. In this study, the CE is considered significant if the possibility that obstacles could cause collision is judged to be more than 50%.

The main advantage of VRE is that testing is performed in a well controlled environment, providing a safer environment for the participants. In addition, the eye and the head can be tracked and monitored (Luo and Peli, 2006). However, there is a major drawback with this method: the virtual environment does not represent the real world with its complex details, including different obstacles with different amounts of contrast. Further, the VRE may not require the same physical motor skills that are required in the real world, such as moving up or down stairs. Finally, the cost of such instruments is expensive in comparison to the indoor/outdoor courses, where inexpensive cardboard can be used to create differently sized obstacles, and where existing obstacles in the surrounding environment can be used.
3.3 The Visual Search Task

The visual search task is a psychophysical approach to assess the ability of the subject to scan. Visual search is a fundamental behaviour that is related to our performance in daily life (Kuyk et al., 2005) and is required in order to locate an object or to avoid an obstacle in our path. Specifically, visual search involves detection, localization and identification of a target against a more complex background (Ball et al., 1988b). Furthermore, it involves cognitive, perceptual sensory and oculo-motor functions; these elements are required while walking. When we are walking, the information within the scene is processed and separated into objects and features, then foveal vision is directed to objects of interest to be localized, identified, and then avoided (Fuhr et al., 2007). The time taken to locate the obstacles (or objects of interest) may be indicative of scanning skill efficiency (Kuyk et al., 2005). Finally, it was found that VI patients search more slowly than subjects with normal vision (Kuyk et al., 2005). This result could indicate that the visual search method is a reliable measure of mobility performance.

There are several reasons to link mobility performance to the impairment of visual search behaviour (Kuyk et al., 2005). Firstly, in cases of VI, VF would be affected, meaning that some objects of interest will fall in scotomatous areas, unseen by the patient until they perform eye and/or head movements. For example, in overall field constriction (e.g. RP), VF would be limited to a few central degrees and eye and/or head movements are required to scan the entire area of interest to perform everyday life tasks. Secondly, visual search performance will depend upon the 'saliency' of the visual features. Some of these features (e.g. colour, orientation, or shape) may be dependent on retinal location (i.e. the highest quality would be in central vision and would decline when going to the periphery). Specifically, patients with central scotoma could find that a visual feature that is highly salient to normally-sighted people is more difficult for them. Generally, in a visual search
test, the subjects are asked to identify targets in the presence of various distracters. The difference between the target and the distracters could be in one visual feature (basic) or in more than one feature. If the difference is basic (e.g. size), then the target stands out more and is determined faster. In this type of search, search time is not influenced by the number of distracters. This is because the basic features (e.g. colour, orientation and size) are extracted in parallel across the VF by the pre-attentive system (Treisman and Gelade, 1980). If the difference lies in two or more visual features, or the ‘saliency’ feature is not noticeable, then the participant may take more time to identify the target due to the nature of the attentive system (guided by the pre-attentive system) which examines the objects one by one to differentiate between targets and distracters (Kuyk et al., 2005).

The main assessment measures in the visual search task are the reaction time (RT) and the accuracy measures. These measures determine the difficulty of the task (Kuyk et al., 2005). The RT is defined as the time between the appearance of the target and the reaction of the patient (Kuyk et al., 2005). The RT can be affected by several factors: set size (the number of items within one display), field size (the size of the display itself), target contrast, target colour, target size, saliency, and familiarity (Fuhr et al., 2007, Chan and Courtney, 1998, Wang et al., 1994). The accuracy measures have been used previously in many studies (Kuyk et al., 2005, Liu et al., 2007, Fuhr et al., 2007). Another important issue is that targets within a visual search test should be distributed in all directions in the field to avoid any systematic errors which may be caused by eccentric viewing (Kuyk et al., 2005).

In general, the visual search paradigm has not been used extensively to assess patients’ mobility performance. However, some studies have used the visual search task as a main measure, either to explore the link between visual search and mobility performance (Fuhr et al., 2007, Bibby et al., 2007) or to assess the effectiveness of optical aids for field constriction
(Drasdo and Murray, 1978, Lowe and Drasdo, 1992b). Fuhr et al. (2007) studied the relation between feature visual search and mobility performance of visually impaired subjects. The study assessed 44 VI patients in a visual search task and an indoor mobility task. Most of the subjects had AMD (32 patients) with a good mean for VA (0.88 ± 0.29 logMAR). The visual search trial consisted of three set sizes (8, 16, and 32) and three field sizes (10°×10°, 20°×20°, 40°×40°). The subjects were asked to look for a 2° × 2° white square (the target) among 1° × 1° square distracters on a black background. The target could appear at any of the 36 positions of the 6 × 6 square grid (Figure 3.4). The subjects were asked to detect the presence or absence of a target in each display in the shortest time possible and then press one of two keys on the PC keyboard. The search performance was assessed by two measures: the percentage of hits (correct indication of the presence or absence of a target on a present-target trial) and the percentage of false hits (reporting a target on a target-absent trial) and the RT (the time needed to detect or reject the presence of a target). Each subject was trained for four days and then tested on the fifth day in order to control variations resulting from learning effects. The mobility course was an indoor high density obstacle course (30.50 metres in length with 60 obstacles). The measures used to assess mobility performance were travel time and the number of contacts. Fuhr and colleagues (2007) concluded that the RT was statistically significantly correlated with mobility performance, with 37.5% to 66.9% of the variation of mobility measures accounted for by visual search speed (from 10° to 20° field size). Their results could indicate the usefulness of this measure to predict mobility performance.
Figure 3.4 The subjects perform a visual search task in a study by Fuhr et al (2007). The patient maintains fixation on the central white square while the various distracters are presented at different positions (Fuhr et al., 2007).

Bibby et al. (2007) explored the relationship between the scanning reaction time (SRT) and self-reported mobility performance. Thirty patients with VI caused by various abnormalities, mostly AMD, were recruited. Scanning ability was tested by the use of a program based on the time taken to scan and sequentially locate four randomly distributed numbers on four black and white photographs (Figure 3.5). The photograph was displayed on a 43cm computer monitor with the participant sitting 40cm away from the monitor. The size of the target was equal to 6/120. Self-reported mobility performance was assessed by the perceived visual ability using the IMQ which was introduced by Turano et al. (2002). (More details about the IMQ are provided in Chapter 4). The study concluded that scanning ability was statistically significantly correlated with self-reported outcome (person correlation = - 0.662, $p < 0.05$). However, the main design constraint in this study was that the four targets had to be located in sequence, which may not be applicable in the real world. Generally, while walking in the real world, people do not usually need to search for obstacles in sequence.
Figure 3.5 The four black and white photographs used by Bibby et al. (2007). Each photograph has four numbers for the patient to sequentially detect and the SRT was recorded.

Drasdo and Murray (1978) evaluated the effectiveness of the reverse telescope by assessing visual search ability in five TV patients (with a VF range from 20° to 60° diameter). In their test four white circular spots were projected onto a 90° × 45° screen positioned at a distance of 1m. The subjects were asked to indicate and describe the position of the spots. The total time taken to complete the 16 slides was recorded. The research trial was performed first without the device (binocularly, and monocularly with the best eye) and again with the best eye looking through the reverse telescope. Drasdo and Murray concluded that the effectiveness of scanning ability improved monocularly, as the mean search time for the five participants was 204 seconds without aid, compared with 108 seconds with the device. However, when they compared the search time in binocular state without aid and in monocular state with reverse telescope, they found no significant difference between them: the mean search time without aid binocularly was 157 seconds.

Lowe and Drasdo (1992b) tested five RP patients (with a VF range from 12° to 28° diameter) to evaluate visual search performance with a binocular reverse telescope. They repeated the trial twice; each trial had 26 target slides mixed with blank field slides. In each slide there
was a white disc presented at one half of the field and the background was an intense black. Within the white disc an upper case letter was presented. The size of the target was determined by accounting for the magnification factor of the reverse telescope (0.33x) and the worst VA of the participants. The subject sat 1 metre from a cylindrical concave projection screen giving a FoV of 90° × 67°. The patients were instructed to search for the target disc, state the letter within and touch the target with a photoresistor wand, whereupon the next target would be presented. The experiment was presented in A-B-B-A sequence, where A signifies without the reverse telescope and B signifies using it. The search time for completing the full trial was recorded. Lowe and Drasdo (1992b) concluded that there was no significant difference in search performance, with and without the reverse telescope.

A further study was conducted by Coeckelbergh and co-workers (2002) to evaluate the efficiency of visual search in patients with VF defects. They introduced the concept of the attended field of view (AFOV). The general concept behind AFOV is based on the useful field of view concept (UFOV): "the total visual field area in which useful information can be acquired without eye and head movements (i.e. within one eye fixation)" (Ball et al., 1988a) although the head and eye movement were allowed in this test. In the AFOV the subjects are asked to search for a target among a number of distracters (Figure 3.6). The RT was recorded and its distribution was measured. The distribution measure was based on the fact that inefficient scanning could indirectly cause presentation time to be longer and/or poorly distributed (Coeckelbergh et al., 2004). For example, the scanning ability of a hemianopic patient could be efficient in the functioning field, but may be unstructured in the lost field. Further, RP patients may have slow organized scanning patterns, or fast unorganized scanning patterns. Therefore, Coeckelbergh et al. (2004) suggested using the percentage deviation from the median (PDM)). The PDM was calculated as the following:
PDM = (Σ |xi - median|/n)/max deviation × 100

xᵢ: deviation from median of each position, n = 19

Equation 4

The PDM was coded from 0 to 100, 0 indicating a flat distribution (i.e. the RT is the same for all targets at different positions) and 100 indicating that the scanning pattern was at the worst grade (i.e. longer RT for half of the field and short RT for the other half). However, there are two limitations which may mask the usefulness of this measure: firstly, it did not account for the effect of target eccentricity on the RT, as longer RT is expected with more peripheral targets and secondly, the presentation time in this test was limited, which may have excluded all the poor performers.

Coeckelbergh et al. (2004, 2002) used a 50cm screen to simultaneously present thirty closed circles and one broken circle (Figure 3.6A). The 31 stimuli were arranged in three elliptical circles around the central one. The FoV tested was 60° × 24°. The subjects sat at 30cm from the screen with both eyes open. The target size varied according to the subject’s VA. The participant was asked to identify the target (the broken circle) presented within a field containing distracters at several eccentricities. The target could have appeared at any one of 20 positions (Figure 3.6B). Finally, the subject was asked to identify the gap direction.
Figure 3.6 A. The AFOV stimulus as presented to the subject. B. The 20 positions that were analysed (Coeckelbergh, 2005).
4 Chapter Four: Self-Reported Mobility Performance
4.1 Introduction

The assessment of functional visual performance (i.e. the performance of everyday tasks that depends to some extent on vision to be accomplished (Bernth, 1981)) can be obtained by three methods (Massof and Rubin, 2001). These are: examiner based assessment, proxy based assessment and subject based assessment (i.e. self reported performance). Examiner based assessment could be classified as either an objective (measured performance) or subjective method (graded performance).

The second approach is proxy based assessment, where the method is directed to a close family member or friend. This method is used either to validate patient response, such as in the study by Odom and co-workers (2004) where they assessed the QoL in children with VI using a questionnaire and then compared the children’s responses with their parents' responses; or where the patient is unable to answer the survey such as in Felius and colleagues study (2004) where the questionnaire was directed to the parents instead of the children.

The third method of assessing functional performance is a self-reported outcome which requires subjects to assess their own ability or inability to perform certain tasks or to decide if the rehabilitation intervention was beneficial for them or not (Massof and Rubin, 2001). This method has often been used to assess the impact of a certain diseases or situations, in addition to the signs and symptoms (Pesudovs and Coster, 1998). The importance of this method stems from the fact that the patient has more understanding of, and is sensitive to, his/her status than a clinical measurement. In other words, a clinical measurement would not represent a full view of the patient's performance (Dickinson, 1998). The self-reported outcome is usually assessed using a validated QoL questionnaire.
4.2 Quality of Life

Quality of life (QoL) is a multidimensional concept which is difficult to define as it can be impacted by many factors. One definition was introduced by the WHO assessment group who defined it as "individuals' perceptions of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns" (The WHOQOL Group, 1996). QoL is influenced by several factors including physical health, economic situation, mental health, education, friends and family, satisfaction, and happiness (Leidy et al., 1999, Camfield and Skevington, 2008). Many researchers have developed subjective instruments (questionnaires) to obtain the patient's view of their QoL (Massof and Rubin, 2001).

During the development process of a questionnaire, the domains of the questionnaire are usually chosen according to the author's field of study and based on the areas that are most important to the investigator. Many research groups have tried to develop standardised health related quality of life (HRQoL) questionnaires and, more specifically, vision related quality of life (VRQoL) questionnaires. Some of these attempts regarding the VRQoL questionnaires will be described.

4.2.1 The Psychometrical Properties of the Questionnaire

From a technical perspective the questionnaire is called an ‘instrument’ and consists of a group of items (or questions) used, as a set, to evaluate a specific function or condition. The instrument consists of multiple items which could be grouped under several domains, each of which represents a specific variable (e.g. distance vision, illumination or mobility). These domains are usually based around a particular functional or visual characteristic. The instrument is considered as a good approach for the evaluation of conditions or hypotheses as long as they fulfill three statistical criteria: they must demonstrate reliability, validity, and
Responsivity (Table 4.1).

Reliability is the first criterion to determine the instrument quality. Generally, reliability is a measure of the consistency of the instrument rather than its construction. Reliability is divided into two main categories. The first category is internal consistency which can be defined as "the extent to which all items measure the same construct (or variable)" (Margolis et al., 2002). Internal consistency is measured using Cronbach's formula for coefficient alpha (Cronbach’s \( \alpha \)). In this formula items under the same domain will be split into two (e.g. odd vs. even numbered items, or first half vs. second half), and the two groups compared as if there were two versions of the domain (Massof and Rubin, 2001). Cronbach’s \( \alpha \) measures the similarity of responses (Massof and Rubin, 2001) and the psychometric standard suggests that Cronbach’s \( \alpha \) should be more than 0.70 for group comparisons (Leidy et al., 1999, Margolis et al., 2002, Mangione et al., 1992, Massof and Rubin, 2001). Some researchers suggest that the Cronbach’s \( \alpha \) should be more than 0.90 when the result is used for clinical decision making (Mangione et al., 1992). However, it is not appropriate for internal consistency to be too high (i.e. more than 0.90) as this would indicate that the response to the items does not vary (Massof and Rubin, 2001). A low Cronbach’s \( \alpha \) value (i.e. less than 0.70) would be indicative of variation in item responses, which may consequently indicate that the response is controlled by factors that are not linked to the variable of interest (Massof and Rubin, 2001).

The second reliability category is linked with producing the same survey result on two occasions under the same conditions (Ellwein et al., 1995, Massof and Rubin, 2001). The method used is to present the instrument to the subjects under the same conditions and circumstances after a period of time. The test would be considered stable and repeatable if the interclass correlation coefficient was more than 0.60 over a two week interval or less (Leidy...
et al., 1999). This method would show the amount of error in the instrument; the error could be random or systematic. Usually repeatability of the instrument would be affected by random error, whereas systematic error would affect the accuracy of the instrument (Massof and Rubin, 2001, Ellwein et al., 1995).

The validity criterion is fundamental for testing the quality of any questionnaire and is related to the accuracy of the instrument (Stelmack J., 2004). The instrument could be considered reliable, yet, at the same time, invalid. One of the definitions of validity is the ability of an instrument to measure what it claims to measure (Ellwein et al., 1995, Massof and Rubin, 2001). Validation evidence is sub-divided into content validity, construct validity, and discriminative validity. Firstly, content validity (or face validity) is supposed to provide evidence that a particular domain or item represents an area of interest and follows the rules of a good questionnaire (Massof and Rubin, 2001, Ellwein et al., 1995). Specifically, whether the instrument reflects the patient’s concerns and interests (Margolis et al., 2002). This evidence is usually hard to prove statistically (Margolis et al., 2002) but can be tested subjectively by pre-using the instrument in the field (Leidy et al., 1999). Secondly, construct validity provides evidence that the choice of the instrument and the response scale is precise (Massof et al., 2007, Ellwein et al., 1995). This can be measured by comparing the instrument output to a gold standard, such as an objective clinical measure, that could indicate the condition’s severity (Leidy et al., 1999). Alternatively, one could compare it to a similar construct instrument (Margolis et al., 2002). Finally, discriminative validity represents the sensitivity of the instrument and helps to confirm its accuracy. An instrument would be considered as discriminatively valid when it is able to distinguish between two groups of subjects by their responses to the questionnaire, and would be able to separate the participants accurately according to their actual group (Ellwein et al., 1995, Massof and Rubin, 2001). For instance, if the scores of the patients with poorer vision are lower than the scores of those
with better vision, the instrument would be considered sensitive (Mangione et al., 1998a). Discriminative validity has been rarely tested in most previous studies and only a few studies have proven their instrument (Mangione et al., 1998a, Mangione et al., 1998b, Steinberg et al., 1994, Mangione et al., 1992).

The responsivity factor is the third measurement of the instrument’s psychometric properties. It is used to assess the outcome of the instrument and give a measure of how sensitive it is in assessing the intervention which has been applied (Ellwein et al., 1995). The instrument would be considered as a sensitive measure if it determines changes that have occurred following an intervention. In general, the responsive factor has only been tested in instruments that were constructed to assess patients with cataracts (Elliott et al., 1990) in which it would be expected that the instrument would be responsive (Margolis et al., 2002).
Table 4.1 The characteristics for HRQoL and VRQoL evaluation in clinical trials.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td><strong>General Validity</strong></td>
<td>Does the instrument measure what it is intended /designed to measure?</td>
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<td></td>
<td>Trial specific: Is the measure appropriate for the patients, setting and</td>
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<td></td>
<td>intervention under investigation?</td>
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<tr>
<td><strong>Content validity</strong></td>
<td>Does the instrument measure HRQoL as generally defined? Are there</td>
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<td></td>
<td>scale scores to represent the physical, functional, psychological and</td>
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<td></td>
<td>social domains?</td>
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<td></td>
<td>Does the instrument reflect the aspects of HRQoL important to the</td>
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<td></td>
<td>patients themselves? Are the key dimensions expected to change with</td>
</tr>
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<td></td>
<td>therapy adequately represented?</td>
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<tr>
<td><strong>Construct validity</strong></td>
<td>Does the instrument behave in a manner consistent with the underlying</td>
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<td></td>
<td>construct of HRQoL? For example, does it correlate with other instruments</td>
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<td></td>
<td>designed to measure constructs related to HRQoL? Does it differentiate</td>
</tr>
<tr>
<td></td>
<td>groups known to differ in HRQoL? Evidence of construct validity is</td>
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<tr>
<td></td>
<td>accumulated over time.</td>
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<tr>
<td><strong>Reliability</strong></td>
<td>To what extent is error present in the instrument?</td>
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<tr>
<td><strong>Internal consistency</strong></td>
<td>To what extent is there consistency within the instrument itself, across</td>
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<td></td>
<td>items within domains, and across all items in the scale? These estimates</td>
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<td></td>
<td>appear as Cronbach’s coefficient alpha (α) and reflect the co-variation</td>
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<td>among the items within a scale.</td>
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<tr>
<td><strong>Repeatability</strong></td>
<td>To what extent is the instrument stable over time? These estimates are</td>
</tr>
<tr>
<td></td>
<td>expressed as intra-class and Pearson correlation coefficients.</td>
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<tr>
<td><strong>Responsiveness</strong></td>
<td>To what extent does the instrument detect change over time with</td>
</tr>
<tr>
<td></td>
<td>alterations in disease state and in response to treatment?</td>
</tr>
<tr>
<td><strong>Respondent burden</strong></td>
<td>What is the time and effort required to complete an instrument?</td>
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</table>
4.2.2 Vision Related Quality of Life (VRQoL)

There are several reasons to design vision-related QoL instruments. Firstly, it has been found that the deterioration of vision affects the patients' scores in the HRQoL (Chia et al., 2004). Secondly, issues affecting the QoL in general health conditions may not be the same as those affecting visual conditions (Frost et al., 1998). Therefore, a generic instrument will not assess all of the limitations that are caused by particular eye conditions. Consequently, the HRQoL would be predicted to have a low responsivity to changes in functional status and the patients' QoL. Further, from a clinical point of view, in clinical studies the visual function measures such as VA and VF are useful in the assessment of a patient's condition. However, these clinical measures may not represent the patient's satisfaction and/or functional limitations (Swamy et al., 2009, Varma et al., 2006, Bernth, 1981, Margolis et al., 2002). For example, Ghazi-Nouri and co-workers (2006) found that the VA was not significantly changed postoperatively following a retinal procedure, yet the score of the National Eye Institute 25 item Visual Function Questionnaire NEI-VFQ 25 as developed by Mangione and co-workers (2001) had significantly improved. There have been many attempts to design different instruments for VRQoL (Carta et al., 1998, Frost et al., 1998, Mangione et al., 1998a, Mangione et al., 1998b, Wolffsohn and Cochrane, 2000, Mangione et al., 2001, Beker et al., 1985, Hart et al., 1999, Hassell et al., 2000, Horowitz and Reinhardt, 1998, Weih et al., 2002). Generally, self-reported functioning and well-being play a crucial role in understanding patient satisfaction and limitations resulting from visual anomalies.

Wolffsohn and Cochrane (2000) designed the LVQOL questionnaire directed to LV patients. Their main purpose was to develop a questionnaire to be used in the assessment of the effects of LV rehabilitation. The items in the instrument were based on the functional dimension. The instrument consists of 25 items, divided into four domains: distance vision, mobility and lighting; adjustment; reading and fine work; and ADL. Dividing the LVQOL into four
sections reduces the amount of information lost and means that responses to items within specific sections can be considered if needed. The patient is asked to rate the problem they have in different situations, from 5 to 1 where 5 indicates no problem and 1 a major problem. In addition, the participants can grade the item as 0 if they can no longer perform the task because of their vision. They could also rate the items as "not relevant" if the item was not relevant to them in their daily lives. The items rated as "not relevant" were given an average score of 3. The LVQOL structure allows it to be scored as a total for the whole instrument, or for each sub-scale individually. The instrument was internally consistent (Cronbach’s $\alpha=0.88$), repeatable (0.72 as measured using the intra-class correlation coefficient), but no evidence was provided for construct validity. The questionnaire was responsive to the change after rehabilitation and was found to be sensitive where it had to differentiate between LV patients and an aged-matched control group. The LVQOL was found to have a significant relationship with the patients' distance and near VA and CS ($r = 0.47, p < 0.001$, $r = 0.47, p < 0.001$ and $r = 0.43, p < 0.001$, respectively). Finally, the authors reported that the LVQOL takes five to ten minutes to complete and would therefore would not over-burden the LV patients.

Sugawara et al. (2010) used the Japanese version of the NEI-VFQ-25 in RP patients to test the relationship between the peripheral VF defect and the patients' scores in the questionnaire. The study included 40 RP patients (with VA of 6/9 or better) and 40 age-matched control participants. The RP subjects were classified according to their VF loss (from grade 0 to 6 as described in Chapter One, section 1.3.1). Any participants that did not fit with this classification were excluded from the study. In their results, the ten subscale composite score (general health and driving subscales were excluded from the study as it was reported that they would not affect the final score) was $68.4\pm15.0$ in RP and $90.1\pm7.4$ in controls. This difference was statistically significant ($p < 0.0001$) which indicates that field loss does affect
the QoL of the RP patients. They reported an inverse relationship between the grade of the VF and the ten subscales composite score ($r=0.519$, $p < 0.0001$), i.e. the smaller the FoV the lower the score in the QoL questionnaire (Sugawara et al., 2010).

4.2.3 Vision Related Activity of Daily Living Questionnaire

The vision related ADL questionnaire has been proposed to assess everyday activities in VI patients. These activities are assessed to explore the patient's capability and limitations. The ADL instruments could be valuable in many ways. Firstly, they give a baseline of patient performance with which to compare at subsequent visits (Dickinson, 1998). This would means that these instruments are useful in the evaluation of the success of visual rehabilitation programs (Sloane et al., 1992, Massof and Rubin, 2001, Bernth, 1981). An example is in Leat et al. (1994), where a VRQoL questionnaire was used to assess the success rates of optometric LV rehabilitation. Secondly, these instruments provide an in-depth history and additional information beyond the standard signs and symptoms used to diagnose a disease (Sloane et al., 1992, Pesudovs and Coster, 1998, Dickinson, 1998). Individuals with the same impairment or disease may have different levels of activity limitation (Ellwein et al., 1995), because people have different interests in their everyday activity and the effect of factors such as motivation and adaptation can be assessed using the questionnaire. This is something which would not be determined by clinical measurements. Finally, questionnaires are useful in developing and testing hypotheses (Sloane et al., 1992). This is because the self reported outcomes offer additional means, beyond the standard clinical measures, to confirm or reject the validity of hypotheses.

Following one of the first attempts to explore visual functioning ability (Bikson and Bikson, 1981), many studies have been conducted which involved several visual abnormalities. These include different conditions such as cataract, glaucoma, and retinal disease. Several other
groups have developed visual performance questionnaires to evaluate the impact of VI on everyday life activities (Szlyk et al., 1990, Ivanoff et al., 2001, Haymes et al., 2001, Stelmack et al., 2004, Marella et al., 2009).

These "general" questionnaires are valid from a statistical standpoint, but their items are designed to be appropriate for any visual condition. Consequently, the items are more general, making it difficult to interpret the information needed regarding the impact of certain specific visual conditions on the subject's QoL. Secondly, it has been suggested that the items that are validated for a particular population may not necessarily be applicable to a different population (Margolis et al., 2002). For example, an instrument which has been developed to assess the geriatric population may not be applicable to adults or young visually impaired people. In addition, the number of items within an instrument is always limited, which makes it difficult to cover all possible activities that are expected to be restricted for each visual condition. Therefore, several researchers have developed condition-specific instruments, several of which have been directed to cataract populations (Bernth, 1981, Elliott et al., 1990, Fukuda et al., 2009, Mangione et al., 1992, Pesudovs and Coster, 1998, Steinberg et al., 1994). These instruments were in a short format (ranging from eleven to twenty items) and the orientation and mobility items sometimes include driving. This is also true of visual function questionnaires directed to populations with retinal abnormality (proliferative diabetic retinopathy (PDR), and age-related macular degeneration (AMD)), which only include two or three items relating to mobility (Russel et al., 1985, Hart et al., 1999, Stelmack and Massof, 2007).

Harper and colleagues (1999) developed a questionnaire that is specifically directed to LV rehabilitation (called the Manchester Low Vision Questionnaire, MLVQ). The MLVQ is divided into three main sections and within each section there are several items. The first
section contains items addressing specific tasks of ADL (e.g. reading and watching TV). The second section consists of items exploring the use pattern of low vision aids (LVAs) (e.g. duration of use) and items directed to exploring the difficulties faced while using the LVAs. The third section contains items that explore the patient's satisfaction after visiting the LV clinic and to assess the subject's knowledge about their eye condition and whether they agree or disagree with a number of statements (e.g. "sitting too close to the TV causes your eyesight to worsen"). The questionnaire was validated in elderly patients with ARMD, however, the authors have suggested that the questionnaire could be used with a more general LV population. The overall validity study showed that the questionnaire has good reliability. However, the questionnaire does not include items that look at mobility performance, probably because so few aids are prescribed for this purpose and because one questionnaire is not expected to cover the whole range of QoL issues in the VI field.

Visual impairment is significantly related to limitation in mobility (Varma et al., 2006), and TV is a leading cause of the difficulty faced in mobility tasks. For example, Szlyk et al. (1998a) concluded that the RP group reported greater difficulty in the mobility category and negotiating steps category than those with juvenile macular dystrophies. Therefore, it is surprising that to date there are only two studies (Szlyk et al., 1997, Turano et al., 1999a) which have used a visual function instrument specifically to evaluate the impact of RP on subject's performance. The instrument used by Szlyk et al. (1997) was used to evaluate the impact of RP on the subject's visual functioning. However, the instrument was not designed for the specific investigated population and was derived from older questionnaires. The instrument also included items that related to central vision and good VA, and it is already commonly known that the RP patients have those abilities (Turano et al., 1999a). This means the subject would be expected to score highly in these items, which may affect the final outcome of the questionnaire. Moreover, the only a few items were linked to O and M (five
out of 57 items) which may not give a comprehensive analysis of patient performance.

Turano et al. (1999a) developed the IMQ which is a 35 item instrument to evaluate thirty five different mobility situations. The patient is asked to rate the difficulty they face in each situation (without any assistance e.g. cane, companion, guide dog) from 1 to 5, where 1 refers to no difficulty and 5 extreme difficulty. They can respond with NA (not applicable) if they cannot perform the situation without an external help, and with X if the difficulty level they feel in performing a certain task is due to a reason other than the visual loss. Turano et al. did not suggest a method to deal with the NA and X scores. This method allowed the investigator to identify which tasks were the most difficult for RP subjects. They identified six tasks that the subjects reported causing difficulty. Those included walking at night, adjusting to lighting change, walking in a dimly lit indoor area, and walking in a high glare area. The questionnaire has been shown to be well constructed, valid, and reliable in assessing independent mobility in RP and glaucoma patients (internal consistency $\alpha=0.95$) (Turano et al., 1999a, Turano et al., 1999b). In their study a good proportion of the variability in the self-assessment of mobility could be accounted for by the visual functions logMAR, log CS, and log retinal area (i.e. correlation with CS $r = 0.54$, $p < 0.01$ and with Log retinal area $r = 0.52$ $p < 0.01$).
5  Chapter Five: Literature Review Discussion, Study Rationale and General Materials and Methods
5.1 Literature Review Summary and Discussion

Patients with VI face multiple limitations while performing everyday life activities. One of these activities is mobility, which affects patients’ independence and QoL. The effect of VI on mobility performance is well documented (Brown et al., 1986, Kuyk et al., 1998, Lovie-Kitchin et al., 1990, Marron and Bailey, 1982, Hassan et al., 2007). One of the main causes of VI is RP which is a degenerative retinal disease that causes photoreceptor loss and, eventually, TV. The effect of RP on mobility has been documented previously (Szlyk et al., 1997, Turano et al., 1999a, Geruschat et al., 1998, Vargas-Martin and Peli, 2006).

There are several optical aids that have been developed which could enhance VF and consequently enhance mobility performance. Some of the reviewed optical aids are, to date, only theoretical approaches, e.g. the poly-powered optical system (Grech, 2001) and the ophthalmic visual field extension device (Paul, 2003), and have not been tested on TV patients. Additionally, some aids have been used only in one patient and have been presented as a case report, e.g. the contact lens telescope in Brilliant and Graf (1978) and minus lens in Kozlowski et al. (1984). However, some of the optical aids discussed were tested in clinical trials to assess their efficacy and these include the Tri-field prism (Stringer et al., 2004, Woods et al., 2010a), reverse telescope (Drasdo and Murray, 1978, Lowe and Drasdo, 1992b), amorphic lens system (Szlyk et al., 1998b) and the peep-hole telescope (Krefman, 1981). Unfortunately some of the reviewed optical aids are no longer commercially available or are commercially rare (e.g. the InWave system, amorphic lenses and reverse telescope).
Most of the studies that have been reviewed investigated optical aids efficacy by:

1. assessing basic clinical objective measures (mainly VF) (Somani et al., 2006, Kennedy et al., 1977, Krefman, 1981, Frith, 1979, Brilliant and Graf, 1978, Hoeft et al., 1985),
2. exploring the patient's mobility performance, e.g. using O&M specialists (Mehr and Quillman, 1979, Szlyk et al., 1998b),
3. collecting basic patient feedback with a short form questionnaire and
4. using a visual search task (Drasdo and Murray, 1978, Lowe and Drasdo, 1992b).

However, these approaches suffer from several limitations. To begin with, traditional visual function measures such as VF and VA cannot indicate the level of improvement that might occur in everyday activities. That is because the patients' response toward the FoV enhancement (for example, partial aperture prism) varies from one individual to another, even if the FoV increased was the same in each case. The performance in everyday activities with the aid varies from one individual to another and sometimes declines because some of them are well adapted patients and the optical aid interferes with their compensatory strategies.

Mobility performance can be assessed using indoor, outdoor and VRE courses, with qualitative or quantitative measures. Qualitative measures have been used in two studies to assess the effectiveness of amorphic lenses and the reverse telescope (Szlyk et al., 1998b, Mehr and Quillman, 1979) respectively. However, other studies have suggested objective measures to assess mobility performance, in terms of efficiency and safety. These measures include travel time, contact errors, PWS, PPWS and VDD. The mobility course could test the subject's performance in a relatively short time following the provision of an optical aid. This approach faces several limitations: the most significant is the lack of standardization, since there is little agreement regarding specific standards of mobility course design. Setting up the course is time consuming, costly (mainly the VRE course) and are difficult to incorporate
Within many clinics due to the limited space available or even because some countries do not permit assessing the patients' performance using a mobility course e.g. Germany.

The VRQoL questionnaire is a subjective method that could be used to determine a subject's capability, limitations, and their contribution to the subject's QoL. In addition, it could be used to evaluate the effectiveness of an intervention. In this project, studies using the visual function questionnaire were reviewed. The aim was to identify the mobility items in these instruments. The aspect of O&M was not included in some of the questionnaires (Beker et al., 1985, Coren and Hakstian, 1987, Nieuwenhuijzen et al., 1991, Newman and Houser, 1991, Turco et al., 1994, Steinberg et al., 1994, Wu et al., 1996, Harper et al., 1999, Long et al., 2000, Dougherty et al., 2009, Brenner et al., 1993), or was not included as a major element of everyday activity (Elliott et al., 1990, Mangione et al., 1992, Pesudovs and Coster, 1998, Fukuda et al., 2009, Hart et al., 1999, Russel et al., 1985, Stelmack and Massof, 2007, Carta et al., 1998, Mangione et al., 1998a, Mangione et al., 1998b, Wolffsohn and Cochrane, 2000, Bergman and Sjostrand, 1992, Steinberg et al., 1994, Marella et al., 2009). The items were very general and did not represent the complexity of the mobility task. A typical example of this is the item included in the study by Bergman et al. (1992) where the subjects were asked "can you walk outdoors?". The shortage of O&M items may be accounted for by the lack of visual rehabilitation aids which deal with mobility function. Moreover, there may be an assumption that a LV patient is not completely independent and so the investigators did not include any mobility tasks. Overall, in order to evaluate the effectiveness of an intervention using the VRQoL questionnaire, the instrument should be valid, reliable and sensitive, and it should be used in long term evaluation. This is because subjects must be given time to be trained and/or adapt to the device in order to answer all the items in the instrument.

The visual search task has been suggested to evaluate scanning ability, which is a crucial
element of efficient mobility. This means that mobility performance could be assessed indirectly. In previous visual search trials, the subject was requested to determine the presence or absence of a particular target among various distracters. The measure of the visual search performance involves the RT and an accuracy measure. There are only four studies that used visual search in order to assess mobility performance (Fuhr et al., 2007, Bibby et al., 2007) or to evaluate the effectiveness of optical aids for TV (Drasdo and Murray, 1978, Lowe and Drasdo, 1992b). The visual search tasks that have been used previously had several limitations in their design, which include their scoring techniques, how to take into account the target location, the involvement of hand movements which require eye and head coordination, recognizing letters which depend on VA, combining the target within distracters which depend on saliency detection and VA. These limitations will be discussed in more detail in Chapter Nine.

Interestingly, the papers that were reviewed in this project were not randomized controlled studies. A cross-sectional design was used and this could indicate the difficulty in recruiting a large number of TV participants in order to assign them to different groups. This is could be because the targeted conditions (e.g. RP) are rare and heterogeneous conditions. This factor could be one of the challenges faced in recruiting the TV patients in our project.
5.2 Study Rationale, Aims, Design and Hypotheses

In LV clinics at the present time, the efficacy of these aids cannot be determined without extended wear. This means that the optical aids are given to patients, who then wear them at home for few weeks or months in order to assess their response towards them. In addition, at the time of writing there were a limited number of studies assessing the efficacy of optical devices in patients with TV based on objective measures. These measures vary in design and are not standardized or easy to adopt in a clinical setting. Therefore, a contribution opportunity was identified to design a standardized clinical test to investigate the efficacy of optical aids. In this project we propose a new test based on the visual search paradigm that avoids the limitations of previous designs and can be used to assess the efficacy of optical aids in TV patients. This design aims to be a new Assessment of Visual Awareness (AVA) test for patients with TV. The new test aims to be valid, sensitive, take a short time to conduct, and be easily adopted in the lab or clinic. This would enable us to assess optical aid efficacy objectively without the need for an extended period of wear. A secondary aim of this project was to investigate the usefulness of optical aids in patients with TV. In this study, the efficacy of two optical aids for TV patients is investigated using our new method. These optical aids are: the partial aperture prism and the Tri-field prism. It was not initially planned to use the reverse telescope, since it was not commercially available in the UK at the time we began the study.

The validity and sensitivity of the assessment of visual awareness (AVA) test were tested in patients with TV caused by RP, Usher syndrome or choroideremia. These targeted ocular diseases usually cause TV, yet VA is preserved even in the advanced stages. A relatively good VA would be required either for the purpose of performing the required tests or due to the expected benefits of using the optical aids (namely Fresnel prism or reversed telescope), as these optical aids can markedly influence the participants' VA. Patients with poor VA are
not expected to benefit from the optical aids proposed to enhance mobility performance. In this study, patients with TV are referred to as TVPs solely for ease of pronunciation and not because we wish to define patients by their condition. We recognize throughout that the participants are people and ensure that they are treated with respect. The AVA test was also tested by a group of normally-sighted participants, whom we have named the simulated impairment participants or SIPS. The SIP group was used in this project for two reasons: 1) the targeted ocular diseases which cause TV are rare conditions and recruiting patients in the advanced stages who also lived locally was expected to be very challenging and 2) in the SIP group factors such as adaptation, VA and CS would not influence the AVA test scores. Besides that, a larger number of participants could be recruited which would provide the required statistical evidence of the AVA test's sensitivity and validity.

As mentioned earlier, TVPs have been found to have difficulty in moving about (Haymes et al., 1996, Black et al., 1997, Turano et al., 1999b, Geruschat et al., 1998). However, the suggested visual limits when the VF loss would impact mobility performance have varied between studies. Faye (1976) stated that "a patient needs 20° or more of central field to orient himself rapidly in his surrounding". Lovie-Kitchin et al. (1990, 2010) suggested that the patients with peripheral loss or mixed peripheral and CFL would be at risk of mobility difficulty when the VF is between 31° to 40°. Hassan et al. (2007) reported that the VF required for effective navigation would vary according to the contrast level, and suggested that the FoVs needed are 32°, 18.4° and 10.90° diameter for low, medium and high contrast levels, respectively. Because of the CS limitations apparent in most RP patients, this would indicate that RP patients with FoV of 32° or more could navigate their way effectively. From a clinical point of view, a residual 20° central FoV is suggested as the stage at which patients usually seek visual rehabilitation (Cohen, 1993, Dickinson, 1998). Based on these findings, participants with TV were recruited with a habitual binocular FoV of 20° diameter or worse,
and a complaint of mobility difficulties. The FoV of each of the SIPs was artificially constricted, using simulators, to 20°, 15°, 10° and 5° and the tests were repeated at each FoV. This FoV size was chosen in order to ensure that mobility performance would be compromised. This would mean that most of the participants in this project fell within the 5th and 6th grade of VF loss (Table 1.4 and Figure 1.2). In terms of classifying our RP participants, most of them are expected to be SI participants rather than SSI participants as the VA is required to be preserved in this project.

In terms of the visit routine, the SIPs were tested on two visits, while the TVPs were tested for up to three visits. The SIPs performed the same tests (i.e. AVA test, mobility test and VF) on both visits in order that repeatability could be determined. The second visit of the TVPs was used to investigate the impact of one of the optical aids on both AVA scores and mobility performance, and if they agreed to take the optical aid home, a third visit was arranged and they then performed all the main tests again on their third visit, after having adapted to the aid.

To test the validity and sensitivity of the AVA test, a series of studies was conducted. In these studies, different relationships and repeatability were tested. To begin with, the relationship between the AVA scores and the FoV was investigated in both TVPs and SIPs. The SIPs scores on both visits were tested for repeatability. The TVPs also attended twice to explore the change in performance after introducing the optical aids. A new easy to set up indoor mobility course was designed. The course sensitivity was investigated in a pilot study and in a larger sample (including SIPs and TVPs). The links between the mobility scores, in both the TVPs and the SIPs, and the AVA scores were investigated in order to establish the validity of the new test.

In addition, the relationship between the AVA scores and scores on two previously validated
questionnaires was explored, i.e. the IMQ (Turano et al., 1999a) and the LVQOL (Wolffsohn and Cochrane, 2000) (Appendix One). The IMQ is the only available questionnaire at the present time that is directed towards the task and the population that is targeted in this study. This questionnaire has been shown to be well constructed, valid, and was reliable for assessing independent mobility in RP and glaucoma patients (e.g. internal consistency $\alpha=0.95$, correlation with CS $r = 0.54$, $p < 0.01$ and with log retinal area $r = 0.52$ $p < 0.01$) (Turano et al., 1999a, Turano et al., 1999b). It is a 35-item instrument that assesses the patients' feelings about various mobility situations. Turano et al. did not suggest a method to deal with the NA and X scores, therefore, in our study the items with these response were removed from the analysis. It is hoped that the questionnaire will be used to classify the TVPs into patients who scored high scores and patients who scored low scores. This result may enable us to potentially know the patients who are "well adapted" and those who are "poorly adapted" to their condition. The LVQOL is the second questionnaire used in this study (Appendix One). The questionnaire consists of 25 items divided into four sub-scales. These are: (1) distance vision, mobility, and lighting, (2) adjustment, (3) reading and fine work and (4) activities of daily living. The items rated as "not relevant" were given an average score of 3, as suggested by Wolffsohn and Cochrane (2000). This particular questionnaire was chosen for several reasons: the items within the instrument were directed to functional dimensions, and not so much to social and/or psychological dimensions. The LVQOL structure allows the scores to be calculated as a total score for the whole instrument, or for each subscale individually. The LVQOL has been tested for interviewer, telephone and self-administration. Further, De Boer and co-workers stated, after rating the questionnaires that are directed to low vision patients, based on psychometric aspects, that at that time, the LVQOL was the best questionnaire for use with low vision patients (De Boer et al., 2004). For the LVQOL, content validity was high and the reproducibility was good, yet no evidence
was provided for construct validity. Finally, the questionnaire was responsive, sensitive and has been found to be related to the patient's visual functions.

A further experiment was conducted to explore the learning effect and its influence on repeatability in both the AVA test and the indoor mobility course. One participant was recruited to visit our lab every day for six consecutive days. The participant mobility scores are expected to be significantly influenced by the learning factor, but the AVA scores less so. This is because the peripheral targets in the AVA test will be presented in random order, hence the participants cannot use a pre-planned strategy, whereas the mobility course will be set up with the same layout, and therefore the participant can build up experience over a period of time. This would provide evidence that the AVA test is consistent and reliable and that it could be used to assess rehabilitation success.

From the data collected from the two participant groups a number of hypotheses are expected to be tested. These hypotheses are:

1. The AVA test scores in both TVPs and SIPs are expected to be significantly correlated with the extent of the FoV. The score should vary proportionally with the target location, with detection time (DT) being progressively longer as targets become more peripheral. This expected result would indicate that the AVA test is a sensitive measure.

2. The SIPs AVA test scores on the second visit are expected to remain stable and thus indicate that the AVA test is minimally influenced by the learning factor, which could point to the AVA test as being a reliable measure to assess optical aid efficacy for patients with TV.

3. TVPs’ AVA test scores are expected to be better than those of SIPs with equivalent field loss because patients with "real" visual defects are expected to be "well-adapted"
to their visual loss. This result would indicate that the AVA test is a sensitive measure and can differentiate between participants based on their familiarity to the condition, despite the fact that they share the same VF loss.

4. The new design of the mobility course is expected to be a sensitive measure. The mobility scores and the extent of the FoV will be correlated for both SIPS and TVPs.

5. The AVA test scores in both SIPS and TVPs are expected to significantly correlate with the mobility course scores on the indoor mobility course. This result could show that the AVA test is valid, and could be useful in the clinical environment.

6. TVPs who scored low scores on the IMQ and were graded as "poorly-adapted" on that basis would be expected to have poorer AVA test scores than the "well adapted" patients. This result would provide evidence for the sensitivity of the AVA test.

7. TVP scores on the AVA would be expected to have a good relationship with the scores on the LVQOL first domain (i.e. distance vision, mobility, and lighting), but not with the other three domains. This is because the first domain involves several requirements that would impact the performance on the AVA test while the other three domains would not demand the same requirements. This result would signify that the AVA test is a specific measure.

8. There should be a change in AVA test performance with the use of optical devices designed to improve the mobility of TVPs, which would indicate that the test is potentially a useful clinical test.

9. It is possible that performances in both the AVA and mobility tests of TVPs who scored highly in the IMQ questionnaire would not improve greatly, or may even decrease, whereas participants who scored low scores would show a greater improvement when optical aids were used. This would be because the aids do not help, or may hinder, patients who have already adopted various eye and head
movement strategies to enable them to perform every day activities safely.

10. In analysing relationships with clinical measures, the AVA test results would perform in the same way as the results from the mobility course and therefore could be used as an alternative to the mobility course.

11. The reliability of the AVA test as a predictor of long-term rehabilitation success will be further assessed using correlation of the change in the AVA test scores when wearing the aid, with the objective and subjective performance after using the aid for several weeks.

The performance of participants with hemianopia in the AVA test is also investigated. The participants were recruited from patients attending the University of Manchester LV clinic. This experiment is expected to provide further evidence of the importance of the AVA test. This is because the AVA scores should be significantly different between the stimuli presented in the functioning field and those that fall in the non-functioning area.

A favourable ethical opinion was given by the University of Manchester Research Ethics Committee (reference number:10127) (Appendix One). The tenets of the Declaration of Helsinki were followed, and all participants gave their informed consent after the possible consequences of the study were explained in detail (Appendix One).
5.3 Methodology of the Main Study

The design and validation procedures of the mobility course and the AVA test are described in Chapters 6 and 8 respectively. The inclusion and exclusion criteria, participant recruitment and visit routine are described below.

5.3.1 Inclusion and Exclusion Criteria

The SIPs

1. No history of ocular disease.
2. Adequate physical ability to perform the mobility course (to be decided based on history taken from the participant).
3. Normal visual function: a best-corrected central VA better than 6/9 in at least one eye (i.e. right eye (RE)), wearing spectacles or contact lenses (if required).

The TVPs

1. Formally diagnosed by an ophthalmologist with RP, Usher syndrome or choroideremia.
2. A remaining binocular VF of 20° or less (confirmed by binocular Bjerrum VF).
3. A best-corrected central VA better than 6/18 in at least one eye with ordinary spectacles or contact lenses.
4. Adequate physical ability to perform the mobility course (will be decided based on history taken from the participant).
5. There are additional criteria that could exclude TVPs or SIPs from the study to be decided based on the patient's history taken on the first visit:
   i. Non-English speakers were excluded as the IMQ and LVQOL are only available in English and this may also influence communication between the examiner and the participant during the experiments.
ii. Participants with poor hearing, to the extent that normal conversation is not possible, will be excluded because the participants would not be able to hear the experimental procedures and instructions.

iii. Participants with disabilities such as learning disabilities, to the extent that it may prevent participants from living independently or moving about. This is because the study involves a mobility questionnaire which requires the answers to be influenced by vision rather than other factors.

iv. Epileptic participants or migraine sufferers, as the study involves flashing bright targets that may negatively influence those participants.

5.3.2 Participant Recruitment

Two different approaches were taken to recruit SIPs and TVPs for this study.

SIP Recruitment

The majority of the SIPs were students and staff from The University of Manchester. Advertisement posters were displayed around the university campus, and an email was sent via the university announcement service to call for healthy volunteers.

TVPs Recruitment

The recruitment of the TVPs was expected to be difficult. The targeted ocular diseases that cause TV are low-incidence conditions, and this creates a heterogeneous population in terms of remaining visual functions. Therefore, we expected challenges in recruiting a sufficient number of patients with TV at an advanced stage.

Eligible patients attending the University of Manchester LV Clinic were given an information sheet about the study by the principal investigator: an email was sent via the university announcement service to call for patients with TV at the university. A blog page was also
created to advertise for study volunteers (http://alialshaghthrah.blog.com/2011/03/05/call-for-rp-volunteer/). This URL link was used as in an invitation letter posted on the wall of the different RP groups via their Facebook pages. The RP groups that were invited included: the Retinitis Pigmentosa Support Group; the Retinitis Pigmentosa Awareness Campaign/Petition; the RP Fighting Blindness (BRPS) Information and Support group; three Retinitis Pigmentosa Groups (three groups with the same name); the Foundation Fighting Blindness group; the Retinitis Pigmentosa and Me group; the I Support the Foundation Fighting Blindness!! group; Friends with RP (retinitis pigmentosa)/Vision Challenges group and the British Retinitis Pigmentosa Society (BRPS).

The study invitation was delivered (either by hand or by email) to 35 patients who contacted us for more information about the study. The patients had retinitis pigmentosa (RP) or Usher syndrome. Twenty-six patients expressed their intention to participate in this study and were asked to visit our lab to assess their eligibility. Six patients were excluded because they were not eligible: two had a FoV larger than the required size (30° and 45°), three had poor VA which prevented them from performing the required tests and using the optical aids and, finally, one patient was excluded because he could only perceive light in one of his eyes, which made using the optical aids difficult. Thus 20 TVPs (9 men and 11 women) were involved in the main study.
5.3.3 Visits routine

Up to three visits were planned to investigate the AVA test and its relationship to the other measures for both SIPs and TVPs.

Visit One

All participants underwent pre-assessment tests and performed the three main tests (i.e. the AVA test, mobility course and VF). The SIPs performed the three tests while using their habitual refractive correction plus the four different levels of simulated FoV constriction in turn, in decreasing order of field size. This means that each participant did the three main tests four times under the simulated conditions. The TVPs performed the three main tests binocularly wearing their habitual spectacles or contact lenses as appropriate.

The pre-assessment tests included optometric clinical tests performed to collect background data and establish eligibility. These tests were:

1. Distance logMAR binocular VA, scored by letter, with habitual spectacles or contact lenses. If the participant is not using spectacles or contact lenses, or if these are more than one year old, the participant was tested to confirm an up-to-date prescription. The VA was measured with logMAR VA ETDRS chart ‘2000’ (Precision Vision, La Salle IL 61301, US).
2. The CS was measured with the Pelli-Robson CS chart at a distance of 1m with overhead illumination (approximately 85 cd/m²) (Metropia Ltd., UK; distributed by Clement Clarke Intl) (Pelli et al., 1988).
3. The Bjerrum VF screen was used to measure the binocular VF in TVPs and the simulated FoV in SIPs while they wore each of the four simulators. The screen was viewed at a distance of 1m and the target used was white, 5mm in size and was moved at 2 deg s⁻¹. A chin and head rest were used.
The TVPs responses to the IMQ and LVQOL questionnaires were collected on the first visit and on the third visit.

The TVPs performed the first three tests binocularly because: 1) the AVA test and the indoor mobility course were assessed binocularly and 2) this is the condition in which the TVPs function in their everyday life. The SIPs were tested monocularly in order to establish which eye would be used for the subsequent experiments. However, if there was no difference between the two eyes and/or signs of amblyopia, the RE was always used. In fact the RE was used for all subjects in this study.

**Visit Two**

SIPs were invited to return to repeat the three tests (AVA, mobility course and VF) in order to obtain data for test repeatability. On the second visit the TVPs performed the tests while wearing either the partial aperture prism or the Tri-field prism (Woods et al., 2010a) (Chapter 2, sections 2.2; 2.2.1 and 2.2.2). The type of optical aid chosen for each participant was selected in alternating order. The partial aperture prism was a 20 Δ and this was chosen because it was expected that this would be the minimum amount of prism power that would produce a noticeable effect (this amount would produce a 10° enhancement), whereas the Tri-field prism power had to be varied in accordance to the VF extent. A 30 minute break was given to all participants, to give them a chance to adapt to the new optical aid. The AVA test was then repeated with this aid in place. The performance on the indoor mobility course was evaluated while wearing the optical aid. At the end of this visit the TVPs were invited to take the aid away and use it as much as possible in everyday circumstances over a period of four to eight weeks. The participants who agreed to this then returned for a third visit to assess the long-term success of the aid. Finally, the TVPs were asked to keep a diary of their use of the optical aids.
Visit Three

The TVPs who agreed to wear their optical aid for an extended period visited the lab for a third time. The AVA test, mobility course and VF were repeated while wearing the optical aid, along with the IMQ and LVQOL questionnaires.

5.4 Simulating Tunnel Vision

The TV was simulated to produce the targeted FoV size. A study was conducted to test the accuracy and repeatability of the FoV achieved (in two different visits) by the simulator in normally sighted participants, using two different methods. These two methods were evaluated to decide which one to use in the main study. Our hypothesis was that the four simulators would produce the targeted FoV and this would be confirmed by both tests on both visits. While designing the simulators, their effect on the VA and CS were explored and it was found that the four simulators would not impact the VA or the CS. It was discovered that finding the letters on the CS chart while wearing the 5° and 10° was difficult, although once the letters were detected they were identified. Based on this, the effect of the simulators on the participants' VA and CS was not investigated.

5.4.1 Simulator Design

Three simulators (opaque circular discs, with a central hole, to fit in a trial frame) were cut from thin polystyrene sheets and were designed to generate an overall field constriction to a 10°, 15°, and 20° residual monocular FoV. A fourth simulator was made from a thicker sheet (50mm) in order to produce a 5° residual monocular FoV. The aperture in the simulators was made in the centre and was an even, complete circle. In the initial test with the simulators, the light was scattered from the inner rim of the aperture. This was therefore painted to eliminate any reflection. A different thickness and material was used for the 5° simulator because the FoV could not be produced with the thinner material. Each simulator was then fitted in the
metallic rim of a trial lens and placed in a trial frame which allowed precise centration of the lenses. The trial lens positioning was set using a lens with a bigger central hole which allowed alignment with the eye, and by adjusting the inter-pupillary distance (IPD). A custom fabric side shield was used, which covered the sides of the trial frame completely, in order to eliminate the possibility that participants would look outside the simulator, and this also cut out any distracting light.

Figure 5.1 The simulators and views
5.4.2 Materials and Methods

In order to verify that the simulators constricted the VF as intended, they were tested in two phases. In the first phase, while cutting the apertures, an Amsler test was performed. The aperture size was calibrated to provide the intended FoV (5°, 10°, 15°, and 20° diameter) at a vertex distance equal to 13mm. After the simulators were painted and ready to use, they were evaluated using the Bjerrum tangent screen and Amsler grid test to verify their accuracy in healthy volunteers. These two methods were chosen because they are practical and quick to use when evaluating participants with TV. The other alternatives that could have been used were the automatic VF analyser (e.g. Humphrey), and Aimark Projection perimeter. These methods are time consuming, however, especially when using an automatic VF (i.e. many targets presented in the non-seeing areas).

Seventeen participants were tested monocularly (RE) with the four simulators with the Bjerrum and Amsler test for each individual. Full correction of the patient's refractive error was incorporated in the trial frame for each individual in addition to the simulator. The different degrees of TV impairment were systematically replicated in each participant by using the four simulators to: 20° diameter (SIPs 20°), 15° diameter (SIPs 15°), 10° diameter (SIPs 10°) and 5° diameter (SIPs 5°) in this order. This means that each participant completed both VF tests four times on every visit. The Bjerrum test and the Amsler test, in each participant, were conducted in alternating order, and the simulators were changed consecutively. For both techniques, the FoV sizes were determined by summing the FoV sizes obtained from each meridian and then averaging them.

Bjerrum tangent screen clinical procedure:

1. The test was explained to the participant thoroughly; emphasizing the necessity for full cooperation and the need to verbally indicate as soon as the white stimulus was
noticed (5mm in size) and the importance of maintaining fixation on the central target and maintaining the head position.

2. The participant was seated and a chin and forehead rest was used to place the participant at a distance of 1m from the Bjerrum screen.

3. The LE was patched with a monocular occlusion (Opticlude eye patch, 3M, UK).

4. The trial frame was worn and the trial frame centration was adjusted.

5. The back vertex distance (BVD) was measured with a millimetre ruler.

6. The habitual refractive error was incorporated in the trial frame.

7. The simulator was placed before the eye, in the front holder, and the fabric side shield was fitted in place.

8. The participant was brought up to the table. The chin rest and table height were adjusted for proper alignment (eye level with centre of screen) and comfort.

9. To monitor the participant's head position, which is a crucial factor and can markedly influence the field size/position, the participant was asked to move his/her head to place a large white pin at the temporal edge of their FoV, where they could barely notice it while at the same time maintaining fixation at the central spot. The first white pin position was determined in accordance to the simulator being tested (e.g. at 10° from the central fixation point for the 20° simulator). Then the white 5mm stimulus was brought from the nasal side and the second horizontal isopter was determined. If the distances from the two horizontal white pin to the central fixation were not equal then they were moved to achieve equality, and the participant was asked to reposition their head in order to place the pins at the opposite edges of their visible horizontal VF. The same procedure was repeated for the superior and inferior directions.

10. The target was moved at a steady rate of 2 deg s\(^{-1}\) from 30° in the periphery (i.e. from
the eight principal meridians, $180^\circ, 45^\circ, 90^\circ, 135^\circ, 225^\circ, 270^\circ, 315^\circ, 360^\circ$) towards the centre. The stimulus always came from a non-seeing into a seeing area. The participant was asked to verbally respond as soon as they noticed the stimulus come into view.

11. The same procedure was repeated for each simulator.

The Amsler grid test clinical procedure:

1. The trial frame was not removed and the LE remained patched.
2. The Amsler chart was placed at 28cm from the participant at the same level of the participant's primary gaze.
3. The participant was kept seated and the chin and head rest was used.
4. The Amsler chart was marked at four locations ($3^\circ, 5^\circ, 7^\circ, 10^\circ$ radius at each direction) with different colours (red, blue, and black, in alternating order) and shapes (circle, cross, in alternating order). This was done to make it easier for the participants, so they did not need to count the number of squares visible in different directions, or move their hand to point to the edge of the field which may influence their fixation and/or head position. However, if the participant could see beyond the marked point s/he could verbally report that by reporting the number of squares.
5. While holding their head and eye steady, the participant was asked to position his/her head so that their visible VF was symmetrical around the centre fixation dot. They were asked to fixate on the central dot and identify how far out from the centre they could see (i.e. the colour/shape of the most extreme visible marker and the number of squares beyond this).
6. The same procedure was repeated for the rest of the simulators.
5.4.3 Results

The participants' ages ranged from 20 to 31 years. The participants' VA in the RE without the simulator was -0.02 ± 0.10 logMAR; (ranged from -0.20 to 0.14). The CS in the RE was 1.75 ± 0.05 log CS (ranged from 1.60 to 1.80 log CS).

The data collected using both tests on both visits were included in the analysis. The data were investigated for normality; the Kolmogorov-Smirnov test showed that the data were not normally distributed ($p < 0.05$), therefore, non-parametric tests were used.

The BVD median ± Interquartile range (IQR) was 13±2.50 mm on both visits. Generally, the simulated VF defect with the four simulators had approximately produced the targeted FoV size (Table 5.1). There was variability of the FoV produced on the both visits with both methods, however, this variation was minimal (about 2 degrees). The measured FoV size was similar using both methods (Table 5.1).

Table 5.1 The FoV sizes Median ± IQR on the first and second visit for both techniques

<table>
<thead>
<tr>
<th>First Visit</th>
<th>Bjerrum SIPs 20°</th>
<th>Bjerrum SIPs 15°</th>
<th>Bjerrum SIPs 10°</th>
<th>Bjerrum SIPs 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median ± IQR</td>
<td>20.50° ± 1.75°</td>
<td>15° ± 1.25°</td>
<td>10.75° ± 1.50°</td>
<td>5.50° ± 1°</td>
</tr>
<tr>
<td>Second Visit</td>
<td>Bjerrum SIPs 20°</td>
<td>Bjerrum SIPs 15°</td>
<td>Bjerrum SIPs 10°</td>
<td>Bjerrum SIPs 5°</td>
</tr>
<tr>
<td>Median ± IQR</td>
<td>21° ± 1.75°</td>
<td>15.25° ± 1.50°</td>
<td>11° ± 1.25°</td>
<td>5.75° ± 1°</td>
</tr>
<tr>
<td>First Visit</td>
<td>Amsler SIPs 20°</td>
<td>Amsler SIPs 15°</td>
<td>Amsler SIPs 10°</td>
<td>Amsler SIPs 5°</td>
</tr>
<tr>
<td>Median ± IQR</td>
<td>20° ± 2.75°</td>
<td>14.50° ± 0.75°</td>
<td>10.50° ± 1.50°</td>
<td>6° ± 1°</td>
</tr>
<tr>
<td>Second Visit</td>
<td>Amsler SIPs 20°</td>
<td>Amsler SIPs 15°</td>
<td>Amsler SIPs 10°</td>
<td>Amsler SIPs 5°</td>
</tr>
<tr>
<td>Median ± IQR</td>
<td>20° ± 2°</td>
<td>14° ± 0.50°</td>
<td>10° ± 1°</td>
<td>5.50° ± 1°</td>
</tr>
</tbody>
</table>

A repeatability test was performed of the FoV size as measured with the same method for the two visits (Table 5.2). The Wilcoxon signed rank test showed that the four simulators as measured by both tests had produced a FoV that is not statistically significantly different between both visits. This result suggests that the FoV simulated is repeatable (Table 5.2).
Table 5.2 A Wilcoxon signed rank test comparing the FoV scores between both visits

<table>
<thead>
<tr>
<th></th>
<th>Bjerrum test</th>
<th>Amsler test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First visit vs. Second visit</td>
<td>First visit vs. Second visit</td>
</tr>
<tr>
<td>SIPs 20°</td>
<td>Z = -1.07, p = 0.28</td>
<td>SIPs 20°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Z = -0.72, p = 0.47</td>
</tr>
<tr>
<td>SIPs 15°</td>
<td>Z = -1.09, p = 0.28</td>
<td>SIPs 15°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Z = -1.65, p = 0.10</td>
</tr>
<tr>
<td>SIPs 10°</td>
<td>Z = -1.24, p = 0.22</td>
<td>SIPs 10°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Z = -0.36, p = 0.72</td>
</tr>
<tr>
<td>SIPs 5°</td>
<td>Z = -0.05, p = 0.96</td>
<td>SIPs 5°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Z = -0.27, p = 0.79</td>
</tr>
</tbody>
</table>

*indicates statistically significant at p < 0.05

A Bland-Altman test was conducted to investigate if the FoV size was in agreement between the two visits as measured by both tests. The test showed that the mean differences in FoV sizes with the four simulators with the Bjerrum and Amsler test between the two visits was negligible. The mean difference ranged from 0 to -0.35°, and from 0.26 to -0.1°, respectively (Figures 5.2 and 5.3). The limit of agreements (LoA) in the Bjerrum with the four simulators (from 20° to 5°) were: -2.60° to 1.90°, -2° to 1.47°, -1.9° to 1.46° and -0.75 to 0.70°, respectively. The LoA in the Amsler with the four simulators (from 20° to 5°) were: -2.19° to 2.67°, -1.6° to 2.2°, -1.7° to 1.49° and -0.50° to 0.48°, respectively. In both methods the points are scattered symmetrically around the mean line which could indicate that the observations on the two visits are in agreement, with either method (Figures 5.2 and 5.3).
Figure 5.2 A Bland-Altman plot comparing the 4 simulator results in degrees, between 1st and 2nd visit with Bjerrum test. The mean line (dashed) is for the pooled data, whereas the mean differences for the four simulators from 20° to 5° are: -0.35°, -0.25°, -0.26° and 0° respectively. The plot shows that the FoVs produced were within the targeted FoV (i.e. 20°, 15°, 10°, 5°) and both scores were in agreement and the majority of the differences between both visits were less than 2°.

Figure 5.3 A Bland-Altman plot for the four simulators with Amsler test. The FoV sizes (in degrees) were compared between first and second visit. The bias line (dashed) is for the pooled data. The mean differences for the four simulators, from 20° to 5°, are: 0.24°, 0.26°, -0.10° and -0.10°. The plot shows that the simulated FoV was in agreement on both visits.
5.4.4 Discussion

The simulators that have been suggested here allowed us to simulate TV. Simulating TV is useful because it can be used to systematically constrict the FoV in normal volunteers. This allows us to control for complex variables (namely VA, CS and adaption level (Haymes et al., 1994).

The FoV, with the four simulators, was constricted to approximately the range targeted for this study (i.e. from 5° to 20°) (Table 5.1). This result was obtained using two widely used and well known methods. In general, the results obtained from this study could provide evidence of the efficacy of the simulators used. Further, the repeatability test has shown that the four simulations as measured by the same method would produce a FoV size that is repeatable (Table 5.2; Figures 5.2 and 5.3). These outcomes provide evidence that the four simulators are reliable, repeatable, and in agreement.

There was minimal variation of the simulated FoV with the four simulators between participants. This change in scores could be due to the change in the BVD from one individual to another. The variation of the BVD has been previously found to impact the simulated FoV (Haymes et al., 1994). Further, in two instances the produced FoV was outside the targeted values. In detail, the average FoV of Participant 7 as measured by both tests was simulated to 26°, 18.25°, 15° and 6.75° and the FoV of Participant 10 was simulated to 25.25°, 18°, 16° and 6.50°. The BVD for those participants was 9mm. The BVD differs between participants and is, unfortunately, difficult to control. Therefore, to try to reduce the impact of the BVD on the simulated VF, the SIPs are divided into four main groups based on the actual VF size obtained in each participant, rather than the intended field size. These groups are: 3°–7°, 8°–12°, 13°–17°, and 18°–22° FoV. Further, there is a chance that the FoV for one participant may fall into the same group twice. Therefore, if a SIP falls into the same
FoV group twice, one of the AVA test results will be removed from the analysis. On the other hand, if a smaller FoV is produced because the BVD is bigger than the expected distance, the simulator is moved from the front to the back lens holder.

The Bjerrum and Amsler tests are useful ways of assessing simulated FoV. The results obtained from both tests were similar. This indicated that just one of them could be used in the main study, in order to not consume the participants' time by repeating the same test twice. The Bjerrum test was chosen for the main study, due to a number of reasons: a larger VF extent can be measured, more meridians will be tested (eight meridians in comparison to four) and the head position is more controlled with this method, using the four white pins. In the Amsler test, on the other hand, the participants' head position may move while moving the hand to identify the extent of FoV. Using the Bjerrum could provide the assurance that the FoV measured is accurate.

Statistical evidence was obtained to show that the four simulators produced the targeted FoV and that these were repeatable. However, the four FoVs simulated are small in size and the differences between them are also small. This means the simulated FoVs are difficult to achieve precisely. However, dividing the FoV size into ranges instead of exact numbers is expected to overcome this limitation. The four simulators will be used in all experiments and any simulated FoV that does not match the targeted FoV will be removed from the analysis.
Chapter Six: A New Approach to Designing a Sensitive and Easy to Set Up Indoor Mobility Course
6.1 The Design Philosophy

The mobility course was chosen to be an indoor one as this gives a number of advantages. An indoor course is more easily controlled in terms of obstacles, degree of complexity, absence of other pedestrians and lighting; and there are no concerns about adverse weather conditions. The outdoor mobility course was not used in this project, although it might have provided a more relevant environment to address the concerns of participants. This is because of the lack of control over many variables (e.g. weather and the presence or absence of pedestrians) which could lead to poor reproducibility and standardisation. Further, some of the outdoor "obstacles" might be dangerous to the participants' safety and health. This new indoor course was designed to be sensitive and easy to set up; the latter was necessary because an important requirement was that the course was to be dismantled after each use, so that it did not require dedicated space. Therefore, it was necessary that it should take only a few minutes to arrange for each participant.

To meet the first requirement, the course was designed to be a challenging one in order to differentiate between good and poor performers, either in the TVP group or in the SIP group. From our point of view, the determinants of mobility course difficulty are: 1) the width of the obstacle course, 2) the number/density of obstacles, and 3) the approach that is used to arrange the obstacles. If the course is too wide, participants can avoid negotiating the obstacles by walking to one side, however, when using an indoor course this factor can be easily controlled. To set up a challenging course also requires an obstacle-rich design. The obstacles should therefore be arranged in a way that is not representative of the natural environment, as this helps to differentiate between various performance levels in a relatively short time and space. It also allows the participants’ ability to be tested many times within a short time to try to avoid the low/negligible number of obstacle contacts that have been reported in previous papers (Black et al., 1997, Kuyk et al., 1998, Lovie-Kitchin et al., 1996,
Geruschat et al., 1998, Leat and Lovie-Kitchin, 2008). The separation distance between the obstacles was kept short, and the obstacles were distributed in such a way that each obstacle was a potential collision. This layout meant that participants had to take repeated decisions to make a change of direction each time with each obstacle, otherwise a collision would be highly probable. If collisions were likely, it meant that all obstacles must be lightweight in order to avoid injuries. The second criterion was to design a course that could be easily replicated. Therefore, a relatively short course that was generally shorter than the previous designs was used in this study. This meant that it would require little space, so that the area could be used for other purposes between experimental sessions. It also meant that other studies could use the same design in different settings. It was particularly important in the current study to be able to replicate the course in a different building because a building move was planned in the middle of the study (an experiment was conducted to show the equivalence of both courses (Appendix Two)).

In this study our new design for an indoor mobility course is evaluated. We hypothesize that this mobility course will be responsive to changes in the FoV size, in that the participants will gradually walk faster as the FoV gets bigger and that the collision incidences will become proportionally greater as the FoV gets smaller. This outcome would provide evidence for the sensitivity of this new mobility course. To our best of knowledge no previous study has suggested a method to validate the mobility course; previous studies which have used a mobility course to assess the functional effect of VF defects have explored the relationship between the participants' performance on the mobility course and the visual function measures, but have not validated their mobility course prior to use.
6.2 Description of the course

The course consisted of a 14m long × 1.45m wide corridor with standard lighting (the mean illuminance was 430 Lux, as measured at 1m from the ground) containing 16 cardboard obstacles, with no pedestrians (Figures 6.1 and 6.2). The floor was covered with a dark coloured carpet (the luminance was 2 cd/m²). The participants walked the same course twice but in opposite directions. The arrangement of obstacles was the same for each participant, in order to standardise the difficulty level. The obstacle heights were:

1. head and shoulder-height objects: four cylindrical obstacles hanging from the ceiling at 145cm to 160cm from the ground which were 5cm to 8 cm wide,
2. waist-height objects: three objects 102cm high and 22cm wide,
3. knee-height objects: four objects 50cm high and 20cm wide and
4. low-lying objects: five objects 8cm to 27cm high, and 21cm wide.

Participants with RP-caused TV reported in a difficulty rating study that these obstacle heights were medium to high difficulty to avoid (Turano et al., 1999a). The obstacle contrast ranged from low to high against the background (six black, six white, and four gray in colour). The Weber contrast of the three obstacle colours were: black 0.60, white 1.90 and gray 1.20.

In this study, travel time was converted to walking speed and then used to calculate PPWS as is widely used in this type of study (Soong et al., 2001, Soong et al., 2004, Black et al., 1997, Leat and Lovie-Kitchin, 2006, Leat and Lovie-Kitchin, 2008, Jones and Troscianko, 2006, Patel et al., 2006, Lovie-Kitchin et al., 1996). The PPWS is calculated by dividing the obstructed route walking speed by the PWS which is the speed on an unobstructed walk of similar length: PPWS = the walking speed in the obstacle course / PWS * 100. The PPWS and the number of collisions were recorded for each direction, and these were referred to as
Part 1 and Part 2. A collision was defined as any contact with an obstacle with any part of the body, a stumble, an unintentional bump into the wall and examiner intervention.

Figure 6.1 The mobility course layout. This shows that obstacle separation varied, but was generally less than 1m. The collarate shapes represent obstacles hanging from the ceiling, the cylinders represent waist-height obstacles, the cubes represent knee-height obstacles and the rectangles the low-lying obstacles.

Figure 6.2 The view of the mobility course layout. The obstacles are randomly distributed within the corridor, yet each part of the path (i.e. start, middle and towards the end) has at least one of each type of obstacle.
6.2.1 The Preferred Walking Speed

The PWS has been used in plenty of studies that have investigated functional performance in patients with VI. The PWS was measured at the beginning of the experiment. The participant was asked to walk for 11 metres from one point to another in a straight line at his/her normal pace. Participants were informed that there would not be any obstacles obstructing their path. This part was repeated and the travel time was averaged to calculate the PWS.

6.2.2 Walking the mobility course

The course was conducted in a quiet area of the building in order to help avoid the presence of pedestrians. The participants were asked to walk the corridor twice but in opposite directions. The participants were asked to walk to the end of the course and then to stop and not turn around until asked to do so. They were informed that there were obstacles randomly distributed which varied in size and colour, and that some of them were hanging from the ceiling. They were asked to negotiate the obstacle course while trying not to contact any obstacle. Further, the participants were not allowed to look at the course before doing the test even while being given the test instructions, to avoid any potential planning of a route in advance.

6.3 Experimental Study

This study was conducted to test the sensitivity and the practicality of the new obstacle course design for our main study.

6.3.1 Materials and Methods

Ten participants with normal visual performance (six men and four women) were recruited from the University of Manchester students and staff. Four grades of TV were simulated, from 5° to 20° in 5° steps, using the method described earlier in Chapter 5, section 5.3. The available FoV was gradually constricted from 20° to 5° for every participant. This means that
every participant completed the mobility course four times. This order was chosen because
the recruited participants were healthy volunteers with no experience of peripheral field loss,
therefore, it was appropriate to give them a chance to become familiar with the new situation.
However, we expected that this adaption would not markedly influence the sensitivity of the
mobility course. This was because the test would only take few minutes which would not be
sufficient time to become a well-adapted participant. None of the participants had done the
experiment or seen the course before, either with or without the simulator. The RE was
always the one used to simulate the TV. The PWS and mobility course were conducted for all
participants.

The participants' visual functions were measured with the same tests. The VA was measured
with logMAR VA ETDRS chart "2000" (Precision Vision, La Salle IL 61301, US). The CS
was measured with Pelli-Robson CS chart at one metre with overhead illumination
(approximately 85 candela (cd)/m2) (Metropia Ltd., UK; distributed by Clement Clarke Intl)
(Pelli et al., 1988). These measurements were taken without the simulators, but with habitual
correction. The VF test was done for every participant, with each simulator, before doing the
mobility course. The VF was measured using the Bjerrum screen and the method used to
calculate the VF size was that described earlier in Chapter 5, section 5.3.2. All participants
satisfied the inclusion criteria (Chapter 5, Section 5.3.1) and the participants’ habitual
corrections were used if they had one.
6.3.2 Results

The participants' age was 22.75±4.00 year (Mean ± SD); ranging from 19 to 30 years. The participants' VA in the RE was -0.05 ± 0.10 logMAR; (ranging from -0.20 to 0.10). The CS in the RE was 1.75 ± 0.10 log CS (ranging from 1.60 to 1.90 log CS). The means ± SD of the simulated FoV for the four simulators of the ten participants were 19.50°±1°, range 18° to 21°; 14.75°±0.75°, range 14° to 16°; 9.50°±1°, range 9° to 11°; and 5°±0.50°, range 4° to 6° respectively.

All the data collected from the mobility course were included in the analysis. The Kolmogorov-Smirnov test showed that the data were normally distributed (p > 0.05), therefore, parametric tests were used.

The PPWS was less than 100%, indicating that the walking speed was slowed down by this new mobility course. The participants had collision incidences but despite the high density of obstacles (16 obstacles) the collision numbers were low. The mean PPWS on the two parts was progressively slower as the available FoV became smaller. For example, there was a 20% difference in PPWS between SIPs 20° and SIPs 5° on the first part (Table 6.1). The collisions scores also behaved as expected, with more collisions being scored the smaller the FoV. For instance, there was a three-fold difference in collisions scores between SIPs 20° and SIPs 5° on the second part (Table 6.1).

Table 6.1 The means ± SD for the PPWS and collision scores on the two parts of the course.

<table>
<thead>
<tr>
<th></th>
<th>PPWS Part 1</th>
<th>PPWS Part 2</th>
<th>PPWS Average</th>
<th>Collisions Part 1</th>
<th>Collisions Part 2</th>
<th>Collisions Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs 20°</td>
<td>62.50 ± 11.00</td>
<td>66.25 ± 13.00</td>
<td>64.50 ±11.25</td>
<td>1.00 ± 0.75</td>
<td>0.50 ± 0.75</td>
<td>0.75 ± 0.50</td>
</tr>
<tr>
<td>SIPs 15°</td>
<td>56.75 ± 12.75</td>
<td>58.75 ± 13.25</td>
<td>57.75 ±12.50</td>
<td>1.25 ± 0.50</td>
<td>1.00 ± 1.00</td>
<td>1.00 ± .50</td>
</tr>
<tr>
<td>SIPs 10°</td>
<td>53.75 ± 12.50</td>
<td>51.75 ± 12.50</td>
<td>52.75 ±12.50</td>
<td>1.50 ± 1.25</td>
<td>1.50 ± 1.50</td>
<td>1.50 ± 1.00</td>
</tr>
<tr>
<td>SIPs 5°</td>
<td>41.75 ± 13.50</td>
<td>43.00 ± 15.50</td>
<td>42.25 ±14.00</td>
<td>2.00 ± 1.50</td>
<td>1.75 ± 1.75</td>
<td>2.00 ± 1.25</td>
</tr>
</tbody>
</table>
**Difference between Part 1 and Part 2**

The scores for the two parts were compared because the participants were to walk the same course twice but in opposite directions, and the PPWS might have been higher or the collisions fewer in the second part because the participants could have learned the course layout. Based on this, two approaches were considered for use in the main study. These were either to consider both parts as one mobility course and record the PPWS and the number of collisions for the 28m course or to record both scores and then average them. The combined scores could be used if there was evidence to confirm that there were no variation in the scores, while the averaged scores would be used if there was a difference between both parts.

Figure 6.3 illustrates the variation in mobility scores between both parts. However, there was no clear pattern to indicate that all the participants were always better on the second part. The variation in PPWS scores ranged from -20% , indicating faster walking speed on the second part, to +15%, indicating faster walking speed on the first part (Figure 6.3). On the other hand, the difference in collisions ranged from -2, indicating more collisions on the second part, to +4, indicating more collisions on the first part (Figure 6.3).

![Fig. 6.3](image)

**Figure 6.3 Differences in PPWS and collisions.** To the left is a histogram illustrating the difference in PPWS between both parts. To the right is a histogram showing the difference in collisions between both parts.
A paired-samples t-test was conducted to determine if the difference in the participants’ performance between both parts was significant. The t-test did not show a statistical significant difference between the PPWS or collision scores for any of the simulated FoV sizes (Table 6.2). Even though there was no significant difference between both parts, a variation in scores was found. We therefore decided to average the scores from both parts to use in further analyses to optimise the robustness of this test.

Table 6.2 Paired-sample t-test comparing the mobility scores between both parts.

<table>
<thead>
<tr>
<th></th>
<th>PPWS</th>
<th>Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs 20°</td>
<td>t (9) = -1.34, p = 0.21</td>
<td>t (9) = 1.46, p = 0.18</td>
</tr>
<tr>
<td>SIPs 15°</td>
<td>t (9) = -1.00, p = 0.35</td>
<td>t (9) = 1.00, p = 0.34</td>
</tr>
<tr>
<td>SIPs 10°</td>
<td>t (9) = 1.17, p = 0.27</td>
<td>t (9) = -0.21, p = 0.84</td>
</tr>
<tr>
<td>SIPs 5°</td>
<td>t (9) = -0.53, p = 0.61</td>
<td>t (9) = 0.46, p = 0.66</td>
</tr>
</tbody>
</table>

* indicate statistical significant, p < 0.05

The averaged PPWS decreased and the number of collisions increased as the FoV decreased. There was a 1.5-fold difference between SIPs 20° and SIPs 5° in PPWS scores and at least a twofold difference between SIPs 20° and SIPs 5° in collisions scores (Table 6.1). The relationship between mobility scores and FoV was investigated using the Pearson correlation coefficient. A statistically significant positive relationship was found between the FoV and PPWS, r = 0.61, p < 0.001 (Figure 6.4). This results indicated that 37% of the variance of both variables was shared. A statistically significant negative relationship was found between the FoV and the collisions, r = -0.40, p = 0.02 (Figure 6.5).
Figure 6.4 The means ± SD of the PPWS scores of the four FoV sizes. This figure shows the positive relationship between the FoV and the PPWS.

Figure 6.5 The means ± SD of the collisions for the FoV 20° to 5°. This figure shows the inverse relationship between the FoV and collisions.
6.3.3 General Discussion

The mobility scores varied between the two parts of the mobility course, however, no clear pattern was found to indicate that the mobility scores were always better on the second run. This result appears to exclude a systematic learning effect which might have been caused by the participants remembering the obstacle locations, or working out an effective strategy to avoid them. This is despite the fact that the course was relatively short: this could have given them a better chance of remembering, but it may also mean that participants did not have the chance to gain experience in navigating the course. It was decided to average the PPWS and collision scores for the two parts to reduce the individual variability of the scores.

A second type of learning effect may be a progressive improvement in performance for each SIP as the participant gained experience in navigating the course: they might have developed strategies to cope with the unfamiliar task and with the restricted FoV. However as the field was progressively reducing, this effect would have improved performance for the smaller FoV and would therefore tend to reduce any relationship between mobility performance and FoV. There is no evidence of such an effect, suggesting that because the course was relatively short, participants did not have the chance to gain any relevant experience.

In this study the VDD as a performance measure was explored in five out of the ten participants. The method used to assess the VDD, the VDD result and discussion are described in Appendix Two. Briefly, it was found that the VDD suffers from several limitations that would not enable us to use it in the main study. Therefore, it was decided to use the PPWS and the collisions scores as our main performance measures.

Mobility performance was responsive to the change in the FoV, with significant relationships being found between the PPWS and collision scores and FoV. However, the relationship between the collisions and the FoV was less marked than the relationship found in PPWS
scores. This could be because there are other factors that influence the collisions scores such as the scanning techniques that were used or the amount of attention they paid while doing the task. The PPWS may be less influenced by these factors as the participant could have decided to be "brave" and try to walk quickly, or could have felt "in danger" and slowed down, yet may still have experienced collisions because they did not have an effective avoidance strategy. In general, the FoV was found to explain 16% to 37% of the variation in both mobility scores. This means that there are other factors that impact mobility performance. These factors were mentioned earlier in Chapter 1 section 1.4.1 and include adaptation, training, confidence and motivation. In addition, as the SIPs performed the test monocularly, the sudden change in the FoV and the sudden elimination of cues could have played a role here. Overall, the results obtained from this study suggest that the mobility course is a sensitive and useful measure. The PPWS and collision scores are used in the main study and also later in validating the AVA test. Finally, the averaged PPWS and collisions scores will be used while analysing the mobility course scores in the main study.

The instructions given to the participants was another issue to learn from and to consider in the main study. For example, one participant stopped walking on contact with one of the obstacles. Therefore, the instructions were repeated to him and we clearly stated that he should keep walking even though he had made contact with an obstacle. Another participant had walked beside the wall with her back towards it in order to avoid navigating the obstacle course and thought that this was a good approach to adopt while doing the test. The test was stopped after a couple of metres and the participant was told that the idea was to navigate her way through the obstacles and the test was repeated. Therefore, a written description and instructions was read to every participant to clearly state what they should do during the test, in order to standardize the instructions for all participants (Appendix One).
Chapter Seven: The Performance of Subjects with Real and Simulated Tunnel Vision in the Mobility Course
7.1 Aims and Hypothesis

The performance of the TVPs and SIPs on the new mobility course will now be explored. In the previous study it was found that the new mobility course design is responsive to changes in FoV. This relationship will be investigated again in a larger sample size and in both the SIPs and in patients with real TV. None of the participants who volunteered in the pilot study were recruited in this study. The repeatability of the mobility course for the SIPs was tested to explore the effect of the learning factor. Only the SIPs were tested for a second time under the same conditions because the second visit for the TVPs was to test the impact of an optical aid on the participants’ performance (to be discussed in detail in Chapters 11 and 12). The relationship between PPWS and collision scores in both groups is investigated here. A good relationship between these measures was expected, since slowing down may indicate that the participant was being cautious and trying to be alert to the obstacles. The relationship between the TVPs’ VA and CS and the mobility course scores will be examined. Only a small to moderate relationship was expected between the variables as the TVPs’ visual function was not likely to vary over a wide range. Finding a small to moderate relationship would be likely to be a result of our inclusion criteria, where only patients with VA better than 6/18 were recruited to this project (discussed previously in Chapter 5, section 5.3.1). Further, this relationship was only tested in TVPs because the SIPs were not expected to show a significant relationship between the visual functions and mobility scores. This is because the SIPs were a homogeneous group of young participants with good VA and CS. The TVPs’ reported outcome was assessed using the IMQ (Turano et al., 1999a) and the low vision quality of life (LVQOL) questionnaire (Wolffsohn and Cochrane, 2000). The LVQOL contains different sub-domains including distance vision, mobility and lighting, adjustment, reading and fine work and activity of daily living (Appendix One). The relationship between the TVPs mobility scores and the QoL scores is investigated with the IMQ scores and with
each one of the LVQOL sub-domains. A moderate relationship was expected with the IMQ scores and the first domain of the LVQOL questionnaire as they consist of items that relate to the ability to move around. Finally, all participants recruited in this study also performed the AVA test and the relationship between the tests is reported in Chapter 9.

7.2 Materials and Methods
The mobility course design and scoring described in Chapter 6 was used in this study. A total of 50 SIPs (28 male and 22 female) and 20 TVPs (9 male and 11 female) were recruited, none of whom had done the mobility course before. The participants were recruited by advertising via the University of Manchester announcement system, through the University of Manchester vision centre clinic, and the RP Facebook groups (the group names are listed in Chapter 5, section 5.4.2). The simulated TV in the SIPs was produced using the method described earlier in Chapter 5, section 5.3. The SIPs were tested on two visits, with a gap between visits of one to two weeks. The SIPs were tested in their monocular state (always the RE) and the TVPs in their habitual binocular state. The PWS was measured for every participant on each visit: the SIPs wore a medium TV simulator of 15° while performing this walk. A standardized description of, and instructions for, the mobility course were read to all participants (Appendix One).

The VA was measured with the logMAR VA ETDRS chart "2000" (Precision Vision, La Salle IL 61301, US) and the CS was measured with the Pelli-Robson CS chart at one metre with overhead illumination (approximately 85 cd/m²) (Metropia Ltd., UK; distributed by Clement Clarke Intl) (Pelli et al., 1988). The SIPs’ visual functions were measured without wearing the simulators. The VF test was done for every participant with each simulator before doing the mobility course on each visit. The VF, in both the SIPs and TVPs, was measured using a Bjerrum screen; the method used to calculated the VF size is described in
Chapter 5, section 5.3.2. All participants satisfied the inclusion criteria (Chapter 5, section 5.3.1). The participants’ habitual correction was worn if they had one.

7.3 Participants' Visual Function Result

In SIPs, no signs of amblyopia were found, full correction (if needed) of the participants’ refractive error was incorporated in the trial frame for each individual. The spherical equivalent (SE) refraction in the RE was: \(-0.75 \pm 1.50 \) Ds (means ± SD) ranging from \(-5.50\) Ds to \(+3.75\) Ds. The TVP means ± SD of the SE refraction in the RE was: \(-1.50 \pm 2.50\) DS ranging from \(-8.75\) DS to \(+2.00\) DS and in the LE was: \(-1.50 \pm 2.50\) DS ranging from \(-7.50\) DS to \(+4.00\) DS. The participants’ ages, and their visual functions are summarized in Table 7.1.

Table 7.1 The participants' ages, VA, and CS.

<table>
<thead>
<tr>
<th></th>
<th>TVPs (Binocular)</th>
<th>SIPS (RE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>42.50 ± 11.00</td>
<td>24.50 ± 6.50</td>
</tr>
<tr>
<td>Range</td>
<td>28.00 to 67.00</td>
<td>18.00 to 51.00</td>
</tr>
<tr>
<td>VA (log MAR)</td>
<td>0.20 ± 0.20</td>
<td>-0.10 ± 0.11</td>
</tr>
<tr>
<td>Range</td>
<td>-0.14 to 0.40</td>
<td>-0.30 to 0.10</td>
</tr>
<tr>
<td>CS (log)</td>
<td>1.50 ± 0.30</td>
<td>1.70 ± 0.08</td>
</tr>
<tr>
<td>Range</td>
<td>0.60 to 1.85</td>
<td>1.60 to 1.95</td>
</tr>
</tbody>
</table>

The simulated FoV for the SIPs four groups (20° to 5°) of the 50 participants were: \(20°\pm1°\) (Means ± SD), range 18° to 22°; \(15°\pm0.75°\), range 13.50° to 16.50°; \(10.50°\pm0.75°\), range 9.50° to 12°; \(5°\pm0.50°\), range 4° to 6°; respectively. The FoV size in the TVP group ranged from 4° to 21°. In detail, five participants had FoV of 4° to 6°, eight participants had FoV of 10° to 12°, and seven participants had FoV of 18° to 21°. None of the TVPs had any functioning peripheral islands of vision.
### 7.4 The TVPs’ Reported Outcome

The TVPs’ reported outcome was investigated using the IMQ (Turano et al., 1999a) and LVQOL questionnaires (Wolffsohn and Cochrane, 2000) which contain different sub-domains. For the TVPs, the median scores of the whole IMQ instrument and the median scores of the whole LVQOL instrument and its sub-domains are summarized in Table 7.2.

#### Table 7.2 The TVPs QoL score in the IMQ, LVQOL questionnaire and in the LVQOL sub-domains

<table>
<thead>
<tr>
<th></th>
<th>Median (range)</th>
<th>Median (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMQ overall</td>
<td>3 (2 to 5)</td>
<td>LVQOL overall</td>
</tr>
<tr>
<td>LVQOL questionnaire sub-domains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>distance vision, mobility and lighting</td>
<td>3 (4 to 1)</td>
<td>adjustment</td>
</tr>
<tr>
<td>reading and fine work</td>
<td>5 (5 to 1)</td>
<td>activity of daily living</td>
</tr>
</tbody>
</table>

IMQ scale range from 1 to 5: 1 represents no difficulty and 5 represents extreme difficulty. LVQOL scale range from 5 to 1: 5 refers to no problem and 1 refers to great problems.
7.5 Mobility Course Results

7.5.1 SIP Results

Approximately 98% of the data collected from the SIPs were included in the analysis. Some of the data were excluded from the analysis due to one of the simulators failing to produce the targeted FoVs. The data collected were explored for normality; the Kolmogorov-Smirnov test showed that some of the PPWS scores were not significantly different from the normal distribution ($p > 0.05$) (in SIPs $20^\circ$, and in SIPs $10^\circ$), whereas the PPWS scores in SIPs $15^\circ$ and SIPs $5^\circ$ were not normally distributed ($p < 0.05$). Further, the collisions data were not normally distributed ($p < 0.05$), therefore non-parametric tests were used throughout.

The PPWS scores gradually decreased as the FoV became more constricted. For instance, the SIPs $20^\circ$ PPWS was 1.50 times faster than the SIPs $10^\circ$ PPWS on the first visit. The number of collisions also increased as the FoV decreased. There were six times the number of collisions for SIPs $5^\circ$ compared to SIPs $5^\circ$. The median ± IQR for all SIPs mobility scores and the change in scores between the first and second visit are listed in Table 7.3.

Table 7.3 The median ± IQR of the SIPs PPWS and collisions on each visit and the difference between them with different simulators

<table>
<thead>
<tr>
<th>FoV</th>
<th>PPWS First visit (Md. ± IQR)</th>
<th>PPWS Second visit (Md. ± IQR)</th>
<th>PPWS Change (Md. ± IQR)</th>
<th>Collisions First visit (Md. ± IQR)</th>
<th>Collisions Second visit (Md. ± IQR)</th>
<th>Collisions Change (Md. ± IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs 20°</td>
<td>51.25±23.00</td>
<td>52.00±27.00</td>
<td>-2.50 ± 18.25</td>
<td>0.50±1.50</td>
<td>0.50±1.00</td>
<td>0.50 ± 1.00</td>
</tr>
<tr>
<td>SIPs 15°</td>
<td>39.75±21.50</td>
<td>41.75±19.75</td>
<td>-0.75 ± 12.75</td>
<td>1.00±1.25</td>
<td>1.00±1.00</td>
<td>0.00 ± 0.75</td>
</tr>
<tr>
<td>SIPs 10°</td>
<td>36.00±23.25</td>
<td>40.00±24.00</td>
<td>-1.00 ± 12.50</td>
<td>1.00±1.25</td>
<td>1.00±1.00</td>
<td>0.00 ± 1.50</td>
</tr>
<tr>
<td>SIPs 5°</td>
<td>24.50±17.25</td>
<td>27.00±14.00</td>
<td>-0.25 ± 7.50</td>
<td>3.00±2.25</td>
<td>2.75±2.00</td>
<td>0.50 ± 1.50</td>
</tr>
</tbody>
</table>
The sensitivity of the mobility course was explored by investigating the relationship between the mobility scores and the FoV using the Spearman Rank-Order correlation test. One of the assumptions of this test is considering the data correlated independent data. However, as the SIPs had done the same course with the four simulators, the relationship between the FoV and the mobility measures might be influenced by the within-participants effect. Therefore, a bootstrap statistic resampling method was used (Wilcox, 2011, Efron and Tibshirani, 1993). The idea behind this test is to divide the sample into four equal groups in accordance with the FoV size, then randomly assign participants inside each group (in each group there were 12 participants). The participants chosen for a particular group did not reappear in any of the other three groups. Then the relationship between the FoV and the mobility scores was investigated using the Spearman test. This test was conducted 1000 times using the R project for statistical computing (http://www.r-project.org/) in order to give all the participants the chance to be included in the test, have a robust result and avoid any impact of the within-participants effect. The reported correlation coefficient value and the significant value are the median of the 1000 values. The Spearman test showed a highly significant positive relationship between the PPWS and FoV, $r = 0.58, p < 0.0001$, $r = 0.56, p < 0.0001$, on both visits respectively (Figure 7.1). This result indicated a higher PPWS associated with a bigger FoV. The collisions were also found to have a statistically significantly negative relationship with the FoV, $r = -0.50, p < 0.0001$, $r = -0.55, p < 0.0001$, on both visits respectively (Figure 7.2). This outcome shows that more collisions occur with a smaller FoV.
Figure 7.1 Relationship between SI FoV and PPWS on both visits. A positive relationship was found between both scores (Spearman's correlation, r = 0.58, r = 0.56, respectively; p < 0.0001).

Figure 7.2 Relationship between SI FoV and collisions on both visits. Negative relationships were found in both scores (Spearman's correlation, r = -0.50, r = -0.55, respectively; p < 0.0001).
The PWS scores were not markedly different from the first to the second visit. The PWS was 1.22 ± 0.19 m/sec (means ± SD) on the first visit and 1.24 ± 0.17 m/sec on the second visit. The PWS scores were normally distributed, and so a paired-sample t-test was used to investigate the difference in performance between both visits, but there was no statistically significant difference in PWS between the two visits, \( t(49) = -0.78, p = 0.44 \).

The difference of SIP PPWS scores between the two visits was explored using a histogram plot (Figure 7.3). The plot shows that the PPWS varied for the same FoV between visits, however, no indication was found that there was always an improvement in the PPWS on the second visit which may refer to any learning experience gained in a short period of time. The difference in PPWS scores between visits was not significantly different across the FoV sizes: ANOVA \( F(3, 191) = 0.26, p = 0.85 \) (The difference in scores was normally distributed). The histogram of the difference in collision scores across the FoV showed that they could also increase or decrease between the two visits (Figure 7.4). However, the mean difference in collisions was positive which could indicate some sort of learning effect, yet it seems that not all the participants gained this experience. The changes in collisions scores were not significantly different across the FoV: ANOVA \( F(3, 191) = 0.54, p = 0.66 \). The differences in scores were normally distributed.
Figure 7.3 The changes in PPWS scores between the two visits with the different simulators. The minus values on the x-axis indicate faster walking speed on the second visit.

Figure 7.4 The changes in collisions scores between the two visits with the different simulators. The negative values on the x-axis indicate more collisions on the second visit.
A Wilcoxon signed-rank test was performed to test the repeatability of the mobility course. The PPWS scores were not found to be statistically significantly different between the two visits for any of the four SIPS groups (Table 7.4). The collisions scores were however found to be significantly different between the visits in SIPS 20° (Table 7.4).

Table 7.4 Wilcoxon Rank Test comparing the mobility scores between the two visits

<table>
<thead>
<tr>
<th></th>
<th>SIPS 20°</th>
<th>SIPS 15°</th>
<th>SIPS 10°</th>
<th>SIPS 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPWS</td>
<td>$Z = -0.54, p = 0.59$</td>
<td>$Z = -0.48, p = 0.63$</td>
<td>$Z = -1.19, p = 0.23$</td>
<td>$Z = -0.97, p = 0.33$</td>
</tr>
<tr>
<td>Collisions</td>
<td>$Z = -2.52, p = 0.012^*$</td>
<td>$Z = -0.96, p = 0.34$</td>
<td>$Z = -0.90, p = 0.37$</td>
<td>$Z = -1.60, p = 0.11$</td>
</tr>
</tbody>
</table>

* indicate significant level, $p < 0.05$

A Bland-Altman plot was used to explore the agreement between the mobility scores on the two visits. The participants' mobility scores on the first visit were compared to their scores on the second. The SIP PPWS scores were plotted in one graph and marked in accordance with their FoV sizes (Figure 7.5). The mean differences for the four SIPS FoV sizes, from 20° to 5°, were: -0.50, -0.10, -1.78 and -0.90, respectively. These mean differences are minimal and the PPWS scores were scattered symmetrically around the mean difference. Further, the difference in PPWS scores between the two visits did not change as the PPWS increased. This suggests that the majority of the SIPS were not noticeably better performers on either visit with any FoV sizes. The LoA varied between the four groups: in SIPS 20° ranged from -24.34% to 23.31%, SIPS 15° ranged from -16.62% to 16.42%, SIPS 10° ranged from -18.48% to 14.92% and SIPS 5° ranged from -13.50% to 11.70%.
Figure 7.5 Bland-Altman test for the four FoV sizes. The dashed line is the mean of difference of the pooled SIP PPWS scores. The mean differences of the four SIPs groups were: -0.50, -0.1, -1.78; and -0.90, respectively. The test showed a good agreement between the PPWS on the two visits in the four SIPs groups. No pattern was found to indicate that the PPWS was always higher on the second visit.

The Bland-Altman test was conducted to explore the change in collisions between both visits. The collision incidences in the four SIPs groups were plotted on the same graph and marked in different colours (Figure 5). The mean differences of SIPs 20° to SIPs 5° were: 0.47, 0.24, 0.28; and 0.50, respectively. These mean differences were small, yet may indicate that there is some sort of learning effect. However, the data points are scattered above and below the ‘mean difference = 0’ line, which indicates that not all the participants were able to make use of the relevant experience. The collisions LoA varied to some extent between the four FoV sizes: SIPs 20° ranged from -1.24 to 2.20 collisions, SIPs 15° ranged from -1.64 to 2.12 collisions, SIPs 10° ranged from -2.1 to 2.65 collisions; and SIPs 5° ranged from -2.81 to 3.81 collisions.
Figure 7.6 Bland-Altman test between the collisions on both occasions in the four SIPs groups. The mean value (dashed line) is the mean of difference of the pooled SIP collisions. The mean differences of SIPs 20° to SIPs 5° were: 0.47, 0.24, 0.28; and 0.50, respectively. The plot showed that the scores were in general agreement and no indications were found to imply that the participants had scored less collisions in the second visit.

A Spearman Rank-Order correlation test was conducted between the PPWS and collisions. Interestingly, no relationship was found between the PPWS and the collision scores within each FoV size (Table 7.5). In general, the approach used to navigate the mobility course varied from one individual to another (Figure 7.7).

Table 7.5 The correlation between the PPWS and collisions scores on both occasions.

<table>
<thead>
<tr>
<th></th>
<th>First Visit</th>
<th></th>
<th>Second Visit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs 20°</td>
<td>$r = 0.03$, $p = 0.86$</td>
<td></td>
<td>$p = -0.17$, $p = 0.26$</td>
<td></td>
</tr>
<tr>
<td>SIPs 15°</td>
<td>$r = -0.20$, $p = 0.15$</td>
<td></td>
<td>$p = -0.04$, $p = 0.80$</td>
<td></td>
</tr>
<tr>
<td>SIPs 10°</td>
<td>$r = -0.02$, $p = 0.90$</td>
<td></td>
<td>$p = -0.13$, $p = 0.40$</td>
<td></td>
</tr>
<tr>
<td>SIPs 5°</td>
<td>$r = -0.20$, $p = 0.30$</td>
<td></td>
<td>$p = 0.10$, $p = 0.70$</td>
<td></td>
</tr>
</tbody>
</table>
Figure 7.7 The relationship between the PPWS scores and the collisions scores in different SIPs groups.
A descriptive plot was used to explore the relationship between the changes in PPWS scores and the changes in collision scores from first visit to second visit (Figure 7.8), but no clear pattern was found between them, suggesting that the changes in PPWS are independent of the changes in collision incidence. It might be expected that slowing down, on the second visit, would lead to fewer collisions, and walking quicker would lead to more collisions. This would mean that the participant should fall in the second and fourth quadrant of Figure 7.8. However, this was not the case and the participants were distributed between the four quadrants. Therefore there is no evidence to indicate that when the participants changed their PPWS scores between visits by slowing down, there was any consequent decline in collision incidences.

Figure 7.8 The relationship between the changes in PPWS scores and the changes in collision scores between both visits in the four FoV sizes.
7.5.2 TVPs Mobility Course Result

All the mobility course data collected from the TVPs were included in the analysis. The data collected were investigated for normality, the Kolmogorov-Smirnov test showed that the mobility scores were distributed normally ($p > 0.05$). Since the TVPs’ performance will be compared to the SIPS performance, the central tendency of the TVPs’ mobility scores were presented as median± IQR. However, a parametric test was used when the relationship between mobility scores and visual function was investigated as these do not involve comparisons with the SIPS.

There was about a two-fold difference in median PPWS across the different FoVs (Table 7.6). The median of the collision scores did not changed markedly as the FoV became smaller, with all collision scores being small (Table 7.6). The frequency histograms of both the PPWS (Figure 7.9) and the collisions (Figure 7.10) showed marked inter-participant variation, regardless of the FoV size that was available to them. The relationship between the TVPs scores and the FoV was investigated using Spearman's rho test. A significant positive relationship was found between the PPWS and FoV, $r = 0.40$, $p = 0.04$. This result indicated that the TVPs were quicker with a larger FoV. The collisions were found to have a weak negative relationship with the FoV, yet this relationship was not statistically significant, $r = -0.20$, $p = 0.28$.

Table 7.6 The Median ± IQR of the TVPs PPWS and collisions with different FoV sizes

<table>
<thead>
<tr>
<th>FoV</th>
<th>PPWS</th>
<th>Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVPs 20°</td>
<td>54.00 ± 18.25</td>
<td>0.50 ± 1.00</td>
</tr>
<tr>
<td>TVPs 10°</td>
<td>60.50 ± 27.25</td>
<td>1.00 ± 1.25</td>
</tr>
<tr>
<td>TVPs 5°</td>
<td>32.50 ± 30.00</td>
<td>0.50 ± 1.25</td>
</tr>
</tbody>
</table>
Figure 7.9 The frequency of the PPWS scores in the TVPs at each FoV size

Figure 7.10 The frequency of the TVPs collision scores at each FoV size
7.5.2.1 Relationship between Mobility Scores and Visual Functions

A Pearson correlation coefficient test was conducted to explore the relationship between the patients' VA, CS and mobility scores. A moderate significant relationship was found between the VA and collision incidences ($r = 0.40, p = 0.03$), but no relationship was found with the PPWS scores. This result indicates that patients who have worse VA scored more collisions. A small to moderate relationship was found between CS and mobility scores, yet this relationship was not statistically significant ($r$ range from 0.20 to 0.30, $p > 0.05$).

7.5.2.2 Relationship between Mobility Scores and Reported Outcomes

A Pearson correlation coefficient test was performed to investigate the relationship between the patients' IMQ and LVQOL scores and their mobility scores. In these questionnaires, the scales used are different from each other. In the IMQ the scale ranges from 1 (no difficulty) to 5 (extreme difficulty) and in the LVQOL questionnaire from 5 (none) to 1 (great problems), therefore, the direction of the relationship was the opposite. In detail, a moderate relationship was found between the median scores of the whole of the IMQ and the mobility scores, yet this relationship did not reach a statistically significant level (Table 7.7). This result indicates that the participants who reported less difficulty in navigation are expected to walk faster and score fewer collisions. In terms of the relationship between the mobility scores and the LVQOL questionnaire, multiple correlation tests were conducted (i.e. with overall scores and with LVQOL sub-domains). Therefore, the Bonferroni correction was applied here and the $p$ value was set to be 0.01. In detail, no significant relationship was found between the mobility scores and the median scores of the whole LVQOL questionnaire (Table 7.7). When the relationship between the mobility scores and the median scores of the four sub-domains within the LVQOL questionnaire was investigated, a significant relationship was found between the collision incidences and the first sub-domain (distance vision, mobility and lighting), yet not with the PPWS. No significant relationship was found
between the mobility scores and the other three sub-domains (Table 7.7). This may suggest that participants who responded with fewer problems to the items in the first sub-domain scored fewer collisions.

Table 7.7 The relationship mobility scores and the QoL questionnaires scores

<table>
<thead>
<tr>
<th>QoL questionnaires</th>
<th>PPWS</th>
<th>Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMQ (whole instrument)</td>
<td>$r = -0.30$, $p = 0.23$</td>
<td>$r = 0.30$, $p = 0.17$</td>
</tr>
<tr>
<td>LVQOL (whole instrument)</td>
<td>$r = 0.10$, $p = 0.36$</td>
<td>$r = -0.20$, $p = 0.10$</td>
</tr>
<tr>
<td>Distance vision, mobility and lighting</td>
<td>$r = 0.50$, $p = 0.02$</td>
<td>$r = -0.60$, $p = 0.001^*$</td>
</tr>
<tr>
<td>Adjustment</td>
<td>$r = 0.40$, $p = 0.06$</td>
<td>$r = 0.10$, $p = 0.40$</td>
</tr>
<tr>
<td>Reading and fine work</td>
<td>$r = 0.10$, $p = 0.10$</td>
<td>$r = 0.10$, $p = 0.35$</td>
</tr>
<tr>
<td>Activity of daily living</td>
<td>$r = 0.01$, $p = 0.23$</td>
<td>$r = -0.3$, $p = 0.23$</td>
</tr>
</tbody>
</table>

* indicate significant level, $p < 0.01$

A Spearman's rho test was used to investigate the relationship between the PPWS scores and the collision scores. A strong negative relationship was found between the PPWS and the collision scores in TVPs 20° and TVPs 5°, yet this relationship was not significant in TVPs 10° (Table 7.8). The shared variance between the two scores in the 20° and 5° groups ranged from 49.00% to 64%. Surprisingly, this negative relationship indicated that the participants who were slower among the TVPs 20° and 5° scored more collisions.

Table 7.8 The correlation between the PPWS and collisions scores on both occasions.

<table>
<thead>
<tr>
<th>Participants</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVPs 20°</td>
<td>$r = -0.74$, $p = 0.03^*$</td>
</tr>
<tr>
<td>TVPs 10°</td>
<td>$r = 0.10$, $p = 0.43$</td>
</tr>
<tr>
<td>TVPs 5°</td>
<td>$r = -0.80$, $p = 0.046^*$</td>
</tr>
</tbody>
</table>

* indicate significant level, $p < 0.05$
The TVPs’ and SIPs’ performances in the mobility course were compared. It was noted that the TVPs walked relatively faster than the SIPs regardless of the FoV size (Table 7.9). For example, the difference between the TVPs 10° and SIPs 10° was about 1.50x. Even though the TVPs walked faster, they did not score more collisions than the SIPs (Table 7.9). These differences in scores were apparent in the scatter-plots (Figures 7.11 and 7.12) where the TVPs’ performances were sometimes better than those found in the SIPs. The difference in performance between the TVPs and SIPs was tested using the Mann-Whitney U test. A statistically significant difference was found in PPWS between the TVPs 10° and the SIPs 10° (Table 7.10). However, no statistical significant difference in PPWS was found with the 20° or the 5° FoV. The Mann-Whitney test showed a statistically significant difference between TVPs 5° and SIPs 5° in collision scores (Table 7.10), but no significant difference was found in the other groups.

Table 7.9 The TVPs and SIPs Md. ± IQR of the mobility scores

<table>
<thead>
<tr>
<th>FoV</th>
<th>TVPs PPWS</th>
<th>TVPs collisions</th>
<th>SIPs PPWS</th>
<th>SIPs collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>20°</td>
<td>54.00 ± 18.25</td>
<td>0.50 ± 1.00</td>
<td>51.25±23.00</td>
<td>0.50±1.50</td>
</tr>
<tr>
<td>10°</td>
<td>60.50 ± 27.25</td>
<td>1.00 ± 1.25</td>
<td>36.00±23.25</td>
<td>1.00±1.25</td>
</tr>
<tr>
<td>5°</td>
<td>32.50 ± 30.00</td>
<td>0.50 ± 1.25</td>
<td>24.50±17.25</td>
<td>3.00±2.25</td>
</tr>
</tbody>
</table>

Table 7.10 Mann-Whitney U test comparing the TVPs and SIPs mobility course scores

<table>
<thead>
<tr>
<th>FoV</th>
<th>PPWS</th>
<th>Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>20°</td>
<td>U=152.00,Z=-0.48, p = 0.63</td>
<td>U=162.00,Z=-0.24, p = 0.81</td>
</tr>
<tr>
<td>10°</td>
<td>U=75.00,Z=-2.65, p = 0.01*</td>
<td>U=181.50,Z=-0.06, p =0.95</td>
</tr>
<tr>
<td>5°</td>
<td>U=89.50,Z=-1.04, p = 0.29</td>
<td>U= 25.00,Z=-2.95, p =0.003*</td>
</tr>
</tbody>
</table>

* indicate significant level, p < 0.05
Figure 7.11 The scatter-plot of the PPWS in the three FoV sizes in both TVPs and SIPs.

Figure 7.12 The scatter-plot of the collision scores in the three SIPs and TVPs FoV groups
7.6 General Discussion

The mobility course test has been widely used as a performance measure in many different forms (Long et al., 1990, Kuyk et al., 1998, Haymes et al., 1996, Geruschat et al., 1998, Turano et al., 1999a, Turano et al., 1999b, Black et al., 1997). This measure of performance has been widely accepted to be affected by a variety of visual defects (Kuyk and Elliott, 1999, Hassan et al., 2002, West et al., 2002, Turano et al., 1999a, Turano et al., 1999b, Black et al., 1997) and be related to several visual function measures (Marron and Bailey, 1982, Brown et al., 1986, Turano et al., 1999a, Turano et al., 1999b, Black et al., 1997). This measure has been used in assessing optical aids that have been proposed to help TV patients while moving about (Szlyk et al., 1998b, Jones and Troscianko, 2006, Stringer et al., 2004). However, the mobility courses used lack standardization as there is no universal design that has been agreed upon as ideal. Further, the mobility course is less adaptable to a clinical/lab setting due to limited available space or even because some countries do not permit assessment of the patients’ performance using the mobility course e.g. Germany (based on a talk that was presented entitled "Rehabilitation in hemianopia" at the 10th International Conference on Low Vision, Vision 2011, Kuala Lumpur, Malaysia, by Prof. Susanne Trauzettel-Klosinski).

The mobility course used in the current study is an indoor course and provides good control over a number of variables, particularly pedestrians, lighting and weather, and it allows the complexity of the course to be pre-determined. Studies such as Turano et al. (1999b), in which the participants were assessed using an outdoor course, reported difficulty in controlling pedestrians, which led to lack of control of the overall complexity. The design of the current mobility course was quite different from previous studies and also represents an unrealistic rather than a natural situation. Specifically, the main two changes introduced here were to test the participants over a relatively short course length (14 metres) and to ask them
to make repeated decisions while navigating the course. These parameters were used with the purpose of really challenging the participants in order to differentiate between them based on their FoV and their adaptation to the situation, where those participants who show confidence and who adopt useful strategies are expected to be more efficient performers in comparison to other participants.

The SIPS were tested in addition to the real patients because the effect of factors such as adaptation, VA and CS could be controlled. Further, this approach gave us the opportunity to recruit a larger number of participants, as the targeted conditions of RP, Usher syndrome and Choroideremia are rare conditions, and recruiting a group of patients who were at a stage when mobility was compromised and who happened to be living in the surrounding area was a very challenging task. A further advantage is that this approach enabled us to systematically constrict the VF to a pre-determined FoV. However, there were a number of limitations to the simulation: the viewing had to be monocular; and the scanning eye movements were very limited, which meant that scanning head movements were needed. In comparison, the TVPs were able to use a much wider range of head and eye movements in their navigation.

The order used to constrict the FoV in the SIPS was a gradually decreasing order, whereas a more conventional experimental design would be to use a random order. This order was chosen because the SIPS were healthy volunteers who had not had the chance to be familiar with the simulated condition, therefore we tried to avoid any excessive disorientation or discomfort while doing the required tests. Thus the SIPS performed the mobility course four times on each visit, which meant that they had a much greater opportunity for familiarization than the TV participants. However, they were no faster than the TV participants, which may indicate the importance of prolonged adaptation. Further, as discussed in the previous chapter (Chapter 6, section 6.3.4), this procedure may have led to a further opportunity to improve
performance as each of the SIPs gained experience in navigating the course. This may mean that they developed strategies to cope with the unfamiliar task and with the restricted field. As the field was progressively reducing, this effect would have improved the performance for the smaller FoV and would therefore mask the relationship with smaller FoV. There is no evidence of such an effect, however, and this may be because the course was relatively short which may indicate that participants did not have sufficient time to gain any relevant experience.

The proposed mobility scores were found to be responsive to the changes in the FoV of SIPs. The mobility scores within the same FoV size in SIPs and particularly in TVPs were spread over a wide range, indicating that the test could distinguish between poor and good performers on the mobility course: there are no floor or ceiling effects. The TVPs scores were to some extent better than the SIPs scores (Figures 7.11 and 7.12). The relationship strength between the mobility scores and the FoV ranged from 0.40 to 0.60. This result could indicate that the FoV is one of the main determinants of mobility performance, yet it is not the only determinant. The relationship strength between mobility performance and FoV, indicates that 16% to 36% of the variation in the mobility scores can be explained by the FoV. This could mean that there are other factors that play a role here such as adaptation (as seen in the TVPs), visual functions (as seen in the TVPs), age, health status and confidence. Besides that, the SIPs performed the test monocularly, therefore the sudden change in the FoV and the sudden elimination cues could have played a role here. Therefore, from a clinical point of view, assessing patients’ VF may not provide sufficient information about their functional performance in everyday activities. Therefore, it may not be enough to assess the VF and disregard observation of the participants’ functional performance and/or the other factors that may influence their performance.
In the SIPs group, it was found that the PPWS gradually decreased as the FoV constricted and more collisions took place with the smaller FoV (Table 7.3). This result was expected based on results that were found previously in the validating study (Chapter 6, section 6.3.3). Both mobility scores have a highly significant relationship with the FoV. However, some participants did not follow this pattern: for instance, Participant 2 maintained a PPWS at about 80% with the first three simulators and did not slow down as the FoV was gradually constricted, scoring three collisions with each of the three simulators. However, when he slowed down with the 5° simulator (PPWS = 40%), more collisions occurred (eight collisions). This performance may indicate that the participant had not adopted a useful strategy to navigate the mobility course but was depending on confidence. Another example is Participant 16, who was a slower walker (PPWS about 20%), yet still had two collisions with the first three simulators and seven collisions with the 5° simulator. This performance would indicate that simply slowing down would not lead the participant to be a good performer. In contrast, Participant 30 walked relatively slowly starting from 40% with the 20° simulator, to 20% with the 5° simulator, while the collisions ranged from zero with the first three simulators and only 0.50 collisions with the 5° simulator. This participant seems to navigate the course slowly but was alert to the dense obstacles that were distributed in the course. It must also be acknowledged that these measures represent a snapshot of performance, and if each of these participants was tested again, there is possibility that some of them may show a completely different pattern of results. However, the general relationship between the FoV and both mobility measures provides evidence that the mobility course is a sensitive measure.

The PPWS scores across the FoV sizes in this study were slower than the PPWS scores in the validating study (Table 6.1, and 7.2). This might be because the number of participants in the main study was larger and therefore their scores varied over a wide range, which would have
impacted the median value. The PPWS scores in the main study should therefore be considered as more representative scores. No marked difference in collision incidences was noticed between this study and the validating study.

The SIPS performance on the mobility course varied between both visits (Figures 7.3 and 7.4). Specifically, the change in PPWS scores was not dependent on FoV size and the repeatability test showed that it was not statistically significant (Table 7.4). Further, the mean difference in the PPWS was minimal and the Bland-Altman plot did not suggest that this change in performance was due to the fact that the participants were always better performers on either visit (Figure 7.5). In the collisions, the change in scores was not dependent on FoV size and the repeatability test showed there was a significant difference between both visits in SIP 20°, yet no significant difference was found with the rest of SIP FoV sizes (Table 7.4). The SIP 20° was always the first test performed, so there is a possibility that this outcome may indicate that there was a learning effect. However about 50% of the participants reported no change in collisions or scored more collisions on the second visit. The calculated effect size (r) was 0.35 i.e. medium effect (Cohen, 1988); this indicates that 55% of the SIP 20° collision scores are overlaps. Additionally, the Bland-Altman plot showed that collision data were scattered around the "difference = 0.34" line, indicating that some participants scored more collisions on the first visit and some participants scored more collisions on the second visit. In general, this change in mobility performance could mainly be accounted for by the fact that the mobility course is a physical and behavioural task, so it could be influenced by factors such as psychological state (people may walk quicker or slower based on their comfort or mood status) and the amount of attention they paid while doing the task.

The change in SIP PPWS scores, between both visits, ranged approximately from ±12.50% to ±24% (Figure 7.5) and SIP collision incidences were within ±2 to 3 incidences across the
different FoVs (Figure 7.6). This amount of variation should be taken into account from a rehabilitation point of view. When the literature was reviewed no certain limit of change was found to be agreed as the limit where we can determine whether or not an optical aid is useful. Therefore, we suggest that the LoA could be used as an indication of rehabilitation success. This means that if professionals want to assess optical aid success using a mobility course, they need to look for an improvement in PPWS of around 15% (which is the amount of variation in SIPs 10°) in patients with 10° FoV. This would mean that the new PPWS score could match the PPWS scores in patients with 20° FoV. This could mean that as a starting point the optical aid needed would be one that could produce an enhancement of FoV by at least 10°, such as a prism with 20 Δ or 0.50X reverse telescope. However, this optical aid may not necessarily enhance everyday functioning but would indicate the starting point and would show the feasibility of this improvement.

In the SIP groups, no relationship was found between the PPWS and collisions (Table 7.5). An inverse relationship may have been expected whereby participates who walk more quickly may score more collisions, and vice versa. This suggests that it is not only the speed of travel which influences collision scores but that there are other considerations such as head movements and the amount of attention the participant pays to the task. Further, looking at the relationship between the changes in SIP PPWS over both visits and the changes in SIP collisions across the different FoVs, no clear pattern was found (Figure 7.8). It had been thought that the participants would walk quicker and score fewer collisions during the second visit as they were more familiar with the sudden loss of FoV and had repeated the course a number of times. This finding could provide further evidence that there was no uniform change in the strategy the participants used to tackle the mobility course over the short period of time during which they were tested.
In the TVP groups, there were inter-individual differences in the mobility scores for each of the different FoV sizes (Table 7.6). The frequency histograms of the TVP mobility scores show this variation at each FoV size (Figures 7.9 and 7.10), which indicates that the FoV may not be the only controller of the mobility scores in this group. There was a positive significant relationship between the PPWS and FoV and a weak but not significant one between the collisions and FoV. It is not surprising that the relationship is less marked than in the SIPS, and could be accounted for by the existence of an "adaptation factor" in this group of participants. These recruited participants are real patients who live their whole life with RP, gradually losing their peripheral field, and who have gained relevant experience and adopted compensatory strategies to varying degrees to help them navigate their way safely and efficiently. Our observations supported this assumption as, for example, TV Participant 9 with FoV 10° scored 60% PPWS and 0 collisions, whereas Participant 14 with the same FoV size walked at slower rate (PPWS= 40%) yet scored more collisions (4). Further, with a FoV of 5°, Participant 20 was a quicker walker (PPWS about 60%) and scored low collisions, about 0.50; whereas Participant 19 walked slowly at a rate of 20% but scored more collisions (2). The results found here are similar to those in three other studies of RP (Black et al., 1997, Haymes et al., 1996, Geruschat et al., 1998). In these studies it was found that the VF extent had a significant relationship with the PPWS (r ranged from 0.34 to 0.70, p < 0.05). In general, this outcome provides further evidence about the sensitivity of the mobility course.

The relationship between the mobility scores and visual functions was explored. The VA was found to have a significant relationship with collisions. A small to medium relationship was found between the CS and the PPWS and collisions, yet this relationship did not reach a significant level (r ranged from 0.20 to 0.30, p > 0.05). The three studies mentioned earlier varied in their findings in terms of the relationship between visual functions and mobility scores. Black et al. (1997) did not find any significant relationship between visual functions
(VA was $0.68 \pm 0.88$ logMAR and the log CS was $1.05 \pm 0.70$) and mobility scores. Haymes et al. (1996) and Geruschat et al. (1998) did however find a significant link between walking speed and visual functions (with the VA, $r$ ranged from -0.60 to -0.70, $p < 0.05$; with the CS, $r$ ranged from 0.60 to 0.70, $p < 0.05$). In Haymes et al. (1996), the VA ranged from 0.00 to 1.60 logMAR and the log CS ranged from 0.00 to 1.85. In Geruschat et al. (1998), the VA was from -0.16 to 1.66 and the log CS from 0.00 to 1.95. Based on that, it seems the reason that this relationship in our study was only moderate or did not reach a statistically significant level could be accounted for by our inclusion criteria. All participants had to have a VA better than 0.40 logMAR and the VF extent was $20^\circ$ or worse which meant that our sample was a more homogenous group and would need a much larger number of participants to reach a statistically significant level. These inclusion criteria were chosen because performing the mobility course was part of a bigger project which included using optical aids. Therefore, a reasonable VA level was required as these optical aids would impact negatively on the VA (e.g. reverse telescope).

The relationship between the mobility scores and the QoL questionnaires was explored. A moderate but not significant relationship was found between the mobility scores and the median scores of the IMQ. A significant relationship was found between collisions and the first domain of the LVQOL questionnaire. No relationship was found with the other three sub-domains of the LVQOL. With the IMQ, not reaching a statistically significant level can be accounted for by the fact that the majority of the participants reported moderate difficulty in the IMQ (11 participants responded 3 on the scale). Finding a significant relationship between the collisions and the first domain of the LVQOL and not finding a significant relationship with the other three sub-domains of the LVQOL may provide an indication of the validity of the mobility course. This is because the first sub-domain involved several factors that would influence performance on the mobility course, e.g. seeing steps and curbs, getting
around outdoors and judging the depth or distance of items (Appendix One) while the other three domains did not have components that would influence a relationship with the mobility course.

The overall relationship between the TVP PPWS and the TVP collision scores was not statistically significant. This could be because of the influence of the TVP 10° scores which fell over a wide range. Therefore the TVPs were divided into three different groups based on their remaining FoV, and the relationships were tested in each group. In contrast to the results found in SIPs, there was a significant negative relationship between the two mobility scores in TVPs 20° and TVPs 5° (Table 7.8). However, no relationship was found in TVPs 10°. This relationship was negative which indicates that the participants who walked quicker scored fewer collisions, which seems counter-intuitive. However, we propose that the participants who walked quicker were more confident and have adopted useful compensatory strategies (e.g. eye and head movements) that allowed them to deal with this completely new situation. This suggestion was supported by the TVPs 20° IMQ scores. Those participants who scored more collisions reported higher difficulty ratings (4 and 5) in comparison to the other participants (2 and 3). However, this finding was not found in TVPs 5°. The TVPs 10° mobility scores did not show any relationship (Table 7.8), but both scores in this group showed considerable variation.

The TVP PPWS was generally faster than that of the SIPs at each FoV (Table 7.9), however, this difference was not statistically significant except for the PPWS scores at FoV of 10° (Table 7.10). The SIP 5° participants scored more collisions than the TVPs, and this difference was statistically significant. Even though the SIPs walked more slowly in comparison to the TVPs, they had more collision incidences. Further, the difference in performance between both TVPs and SIPs is also obvious in Figures 7.11 and 7.12, where the
majority of the TVPs fall in the upper part of Figure 7.11 which means they were within the top performers, and they also fall in the lower part in Figure 7.12 which means they were efficient and travelled more safely than the SIPs. This overall difference in performance across the FoV sizes may show the difference in experience between both groups. The fact that the collision score is sufficiently sensitive to be able to discriminate between groups provides support for the usefulness of this new mobility course.

In summary, this course was found to be sensitive in both control and real patients. This test could potentially differentiate between poor and good performers within each SIP and TVP groups. This design requires little space and could be easily replicated in other studies. The statistical evidence suggests that this test could be used in validating the AVA test (Chapter 9).
Chapter Eight: The Design and Development of the Assessment of Visual Awareness Test
8.1 The Design Philosophy

This project aims to design a new clinical measure which can be used to assess TV patients’ awareness of targets, which is important in safe navigation. The test is based on assessment of the participants’ ability to scan and find targets within and outside their FoV and has been named the Assessment of Visual Awareness (AVA) test. Once this test has been validated, it will be used in this study to determine the efficacy of optical aids for TV patients.

The AVA test is broadly based on the visual search paradigm. The behaviour of visual search has been found to be a good predictor of mobility performance. Studies which have looked at scanning ability (Kuyk et al., 1998, Bibby et al., 2007), feature search (Fuhr et al., 2007) and the UFOV (Leat and Lovie-Kitchin, 2008) have provided evidence to support this finding. Important features which were required of the new test were simplicity, ability to be easily set up in any clinic or lab and that it should enable objective and efficient measurement of performance.

Visual search performance has only been used to evaluate optical aids in two studies in the last four decades (Drasdo and Murray, 1978, Lowe and Drasdo, 1992b), and in a third study to evaluate visual search effectiveness in patients with VF defects (Coeckelbergh et al., 2004). The approaches that have been used in these studies have a number of constraints in their design. Firstly, the target locations were not well controlled due to presenting more than one target in each display (Drasdo and Murray, 1978). Further, the target detection was combined with other tasks (Lowe and Drasdo, 1992a). Lowe and Drasdo asked participants to touch the target and correctly recognize the letter within the target. These two tasks were therefore influenced by hand-eye coordination and VA and may ultimately not be essential to obstacle avoidance or mobility in TV patients. In the study by Coeckelbergh et al. (2004) the target was presented within distracters, and while this test would assess the patient’s ability to
differentiate the ‘saliency’ of the visual features such as shape, size, or colour, these may not be relevant to assessing rehabilitation success.

Various scoring techniques were used in the three studies. Drasdo and Murray (1978) and Lowe and Drasdo (1992b) used the time taken to complete the full test set as their reaction time (RT). Using this method could, however, cause a loss of important information about the RT for individual targets at different eccentricities and its potential change following intervention. On the other hand, Coeckelbergh et al. (2004) set a limited time for every display (from 8ms to 10ms). Setting a limited time may take out all the poor performers and may not adequately assess the improvement of the scores after an intervention. Coeckelbergh et al. used a second measure to assess the participant’s performance, which was the percentage deviation from the median (PDM), intended to assess the distribution of the visual search strategy. The PDM scale ranged from 0 to 100, with 0 indicating that the threshold presentation times were equal for all 19 positions and denoted an efficient performer. The threshold presentation time was defined as the presentation time at which the subject could correctly identify the target in 67% of the trials and this was determined for each of the 19 positions. At the other end of the scale, 100 indicated that the subject responded in maximum presentation time for half of the positions and in minimum presentation time for the other half. This measure, the PDM, does not taken into account differences in RT as caused by the target eccentricity. This means that a target at 20° from the centre would need more time to be seen in comparison to a target at 5°. This limitation would influence the validity of this measure especially if used with TV patients. If this test was used to assess TV patients, none of them would appear as efficient performers and there would be a floor effect of 0%.

The backgrounds used in these studies were either black (Lowe and Drasdo, 1992a) or featureless (Coeckelbergh et al., 2004) which does not represent the complexity of the
environment in which the patient typically functions. Finally, the size of the display that was used in the three studies had a large horizontal extent (60° to 90°), however, the vertical area that was used by Coeckelbergh et al. (2004) may not have had a deep enough area (24°) to measure performance improvement when wearing an optical aid in the real world.

The design of the AVA test attempted to overcome the limitations found in these previous studies. In our test, the target positions were controlled and the DT for every target was recorded. People with visual defects require longer searching times than healthy participants (Zihl, 1995), therefore, participants in our test had unlimited time to respond to each display. Head and eye movement was allowed, meaning that the test allows the use of any compensatory strategies that the participants have adopted. The area tested was 81° laterally × 62° vertically, which is the biggest area that could be produced by using a short focal length projector. This area size was chosen to encourage the use of search strategies, since it is at least three times bigger than the biggest FoV (20°) used in this study. Further, a 60° FoV was appropriate for testing as this is the furthest point of the FoV which still appears to be important to mobility performance (Lovie-Kitchin et al., 1990). The projector used was the Hitachi CP-AW100N (Hitachi, UK), which has a short focal length. The luminance stability of this projector was tested (see Appendix Three).

The main design objectives were:

1. to present two targets in each display for the participants to locate, one at the centre and one at a different eccentricity,
2. to use a complex background that would represent the environment in which the patient lives, and
3. to record the DT of every pair of targets at each location.
The participants were asked to identify the central target as well as to look for the peripheral target. The purpose of presenting a central target in each display was to maintain the central attention, thus ensuring that participants will not detect the peripheral targets by chance. The central target was always presented in the same central position on the background (i.e. the middle of the display) where the participant would be able to detect it immediately after the display was presented. This location was chosen in order not to divert the participants’ attention from their primary objective, which is scanning and detecting the peripheral targets. If this approach were not used, the time taken to locate the central target would have an effect on the DT by recording a slower DT. The shape of the central target was a cross in two orientations (+ or ×), with the + in blue and the × in red. These colours were chosen because they were different to those of the peripheral targets. Altering the orientations would limit the effect of any colour vision defects in case there were any patients with this condition. The participants were to report the orientation and/or target colour. Additionally, changing the target orientation and colour could help maintain the participant's attention on the central fixation. The central target was relatively large, in order to be obvious to the participant and attract their fixation directly the target was presented. Therefore, the cross had an overall arm length of 70mm which represents 3° in size. The central target was presented in random order in conjunction with the peripheral targets.

The position of the peripheral targets is a fundamental issue when testing the entire VF. Therefore, it was decided that the targets should be positioned along eight principal radii, at different eccentricities from the centre. The background was thus divided into four main sections: 1st annulus at 5° radius from the centre, 2nd annulus (10°), 3rd annulus (20°), and 4th annulus (30°). Therefore, 32 positions were identified over the four main annuli. These target positions can also be referred to by their locations on the clock dial. More specifically: the 12 o’clock, 1.30, 3.00, 4.30, 6.00, 7.30, 9.00, and 10.30 positions. These could be used to refer
to the target positions as participants would be familiar with them. This distribution has two advantages: the background can be divided into four equal annuli (each annulus has eight targets), due to an even distribution of the targets at each annulus, and the scores could be compared in relation to their eccentricities which could provide evidence of the test's sensitivity as well as quantifying any rehabilitation success at any of these annuli.

As previously mentioned the participants’ performance was evaluated based on the DT needed to locate every target. From our perspective this measure gives an adequate description of the participants' efficiency in the AVA test. The DT used in the analysis is the median DT of the eight targets presented at each eccentricity for each participant, this is to avoid any variation in scores and maintain the robustness of the DT scores.

In each AVA trial the background slide was continuously presented as a default. The participant was asked to immediately press the response button as soon as they noticed both targets. Then a break slide was presented (i.e. the background), during which responses were collected from the participants. In order to make sure that participants had scanned for the target, they were asked to report the colour and/or the orientation of the central cross. Secondly, the participant was also asked to report the target location as a clock face position and its location in relation to the distance from the centre (i.e. 1st annulus, 2nd annulus, 3rd annulus, and 4th annulus). The DT score was included in the analysis only if the participant correctly reported the main direction of the target (i.e. in which quadrant the target was found), and if the central cross colour or its orientation were accurately reported. This ensured that the participant had scanned for the targets and had not simply looked at the peripheral target by chance, or had guessed.

Image processing software was needed to embed the central and eccentric targets within the chosen background. A Matlab computer program was developed using the Visual Stimulus
Generator (Visage, Cambridge Research System Ltd., UK). This gave the capability to adjust the stimulus size and the background in an efficient way, and to present the test slides in a random order (i.e. chosen by the program). The Matlab program also recorded the DT, and this was automatically sent to an Excel spreadsheet.

With regards to the target size and the background used in this study, two experiments were conducted to determine the appropriate elements for this test.

8.2 Target Size Study

The target was a black and white square which would provide maximum contrast and allow the best chance of detection for patients with reduced CS. Two possible approaches were considered to determine the best size to be used for the AVA target: 1) using a different target size at each annulus in order to take into account the visual resolution decline in the peripheral field, 2) using a fixed target size for all the eccentricities. In addition, it was necessary that all targets were large enough for the participant with the lowest VA (6/18) in our study to be able to clearly detect it.

The philosophy of using a variable target size is based on the observation that the visual resolution declines in the peripheral field (Virsu et al., 1987). This loss of sensitivity may be accounted for by several differences between the central and peripheral field (i.e. changes in cone size, and changes in cone and ganglion cell density) (Gurnsey et al., 2008, Virsu et al., 1987). These differences between the central and peripheral VF lead to differences in retinal sampling processes, or in other words, changes in cortical representation. In order to compensate for these differences the stimulated neural volumes have to be similar to those in the central area of the VF, and to achieve this, the cortical representations of the test targets should be made similar for each retinal location. The appropriate target magnification can compensate for eccentricity dependent sensitivity loss (Gurnsey et al., 2008). This could be
achieved using the linear cortical magnification factor $M$ (Daniel and Whitteridge, 1961, Cowey and Rolls, 1974), which is a scale of mapping from the VF into the striate cortex V1 and is expressed in mm of cortical surface per $1^\circ$ of visual angle. The cortical magnification theory suggests that identical striate-cortical stimulus representations produce identical thresholds at different retinal locations (Rovamo and Virsu, 1979).

Rovamo and Virsu estimated the human cortical magnification factor (Rovamo and Virsu, 1979) and devised a formula to calculate the $M$ value: $M$ superior $\text{VF} = 7.99/ (1 + 0.42E + 0.00012 E^3) ;$ $M$ inferior $\text{VF} = 7.99/ (1 + 0.42E + 0.000055 E^3);$ where $E$ is degree of retinal eccentricity and the $7.99$ mm/deg is the magnification value for the most central fovea. However, the proposed magnification factor is approximate, and one would not expect a perfect estimation as there is variation between subjects in various factors such as neural networking, receptive field size, and sensitivity of the cells, which could all influence the final magnification factor and cannot be measured for every participant (Virsu et al., 1987).

Based on the previous studies, the possibility of using $M$-scaling of the target size was considered. In this study the $M$ values were obtained by averaging the superior and inferior equations of Rovamo and Virsu (1979) and this approach was previously used by Carrasco et al. (1998). The values obtained were used to adjust the AVA target size. As head and/or eye movement were permitted in the AVA test, it would be difficult to determine on which part of the retina the target will be perceived during the test. However, it was decided that the $M$-scaling of the target would be performed for each eccentricity to get the maximum magnification as if the participant was fixating at the centre of the display while the peripheral target falls in the peripheral VF. The target at the first annulus was $0.50^\circ$ in size and this start point was chosen because firstly it is well above the threshold of our participants’ VA (the target is equivalent to 6/36) and secondly no smaller size was available.
due to limitations in the display system (Visage system). The other eccentric positions were M-scaled using the equations mentioned previously, and the sizes for the three eccentric targets were: 0.93°, 1.80°, and 2.70°, respectively at viewing distance of 1.20 metres.

On the other hand, the approach of using a fixed target size was considered for two reasons: firstly, the participants had lost their peripheral field and during the task would be using their central field in combination with head and/or eye movements. This means that the target would be perceived in the central retinal area. This would indicate that the scores would not be influenced by the decline in resolution in the peripheral field. Secondly, this approach would not give the participant any clues as to the target location, i.e. the participant may report the location of the stimulus according to its size instead of actually knowing where the it is. The size used was a 1° target at 1.20 metres viewing distance at all eccentricities.

An experiment was carried out to explore the effect of these two approaches on the DT and on the accuracy of the response. The aim was to find out if there was a difference in performance due to the target size either in the DT scores or in the accuracy of reporting the target location. We hypothesise that there is no difference in DT due to the change in target size as the target is perceived by the central vision. However, detecting the target location might be more accurate in the variable size trials. This is because the variable size gives the participant a clue as to the target location, which may improve their ability to report it. The AVA test is expected to be a sensitive measure in both approaches, by finding that the DT gets progressively longer as the targets become more peripheral.

8.2.1 Materials and Methods

One participant was recruited to make two visits to the lab to investigate our hypothesis. Only one participant was recruited because we wanted someone who was experienced in psychophysical experiments to give the best chance of using the target size to help in
detecting the target location. The participant was tested on two visits in order to find out if he had used the opportunity of his first exposure to the test to help him to improve his ability to detect the target location on the second visit. The participant was tested monocularly on the AVA test with a simulator of 10° residual FoV (as described earlier, Chapter 5; section 5.3), while the other eye was patched. Full correction of the participant's refractive error was incorporated in the trial frame in addition to the simulator. The VA and CS were reduced (using a custom Bangerter foil lens) to 0.38 logMAR, log CS 0.75 respectively in order to approximately match the worst expected VA and CS for the RP participants. The participant was given the AVA test six times for each method at each visit. The background used here was a 1/f noise background (see Section 8.3), because we did not expect the phenomenon to be background-specific. The visual display was a digitally projected using the Hitachi CP-AW100N, at a 100 Hz frame rate onto a 200 ×150 cm opaque screen. The participant sat at a distance of 1.20m from the screen, which gave a presentation area of 81° H × 62° V.

8.2.2 Results

All the data collected on both visits were included in the analysis. The data collected were explored for normality. The Kolmogorov-Smirnov test showed that the data were normally distributed ($p > 0.05$), therefore, parametric tests were used.

The 1st annulus DT of the variable target size was markedly longer, by a factor of approximately four, compared with the DT with a fixed stimulus size on the two visits (Table 8.1). However, the DT was found to be similar for the variable and fixed target size at the rest of the annuli (Figure 8.1, Table 8.1).
Table 8.1 Means ± SD of the DT at each annulus on the first and second visit

<table>
<thead>
<tr>
<th></th>
<th>1st Annulus</th>
<th>2nd Annulus</th>
<th>3rd Annulus</th>
<th>4th Annulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Visit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable size</td>
<td>4.29 ± 2.70</td>
<td>4.580 ± 1.98</td>
<td>7.83 ± 1.24</td>
<td>7.76 ± 1.39</td>
</tr>
<tr>
<td>Fixed size</td>
<td>0.93 ± 0.13</td>
<td>4.03 ± 1.94</td>
<td>7.47 ± 1.84</td>
<td>8.57 ± 4.34</td>
</tr>
<tr>
<td>Second Visit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable size</td>
<td>3.21 ± 1.99</td>
<td>8.89 ± 2.35</td>
<td>9.74 ± 2.91</td>
<td>10.36 ± 1.32</td>
</tr>
<tr>
<td>Fixed size</td>
<td>0.90 ± 0.13</td>
<td>8.30 ± 4.26</td>
<td>8.86 ± 1.90</td>
<td>11.19 ± 3.88</td>
</tr>
</tbody>
</table>

Figure 8.1 A histogram plot of the DT at different eccentricities with variable and fixed size approach. The DT collected on the first and second visit was pooled for presentation purpose.

A two-way analysis of variance (ANOVA) was conducted to explore the impact of the target location and target size on the DT. The ANOVA test suggested that there was no significant statistical evidence that the target size impacted the DT scores on either visit, $F(1,88) = 3.50, p = 0.07$. However, this is an overall result and a planned comparison was conducted to explore if there was a significant difference in the DT between the two approaches (i.e. variable size compared to fixed size) at each eccentricity on the first and second visit separately. A paired sample $t$-test was used and the test showed that the DT was statistically
significantly different between the two approaches at the 1<sup>st</sup> annulus on both visits, but there was no difference for any of the annuli at either visit (Table 8.2). Finally, the ANOVA test showed that there was a statistically significant impact of eccentricity on DT scores with both approaches, $F(3,88) = 34.49$, $p < 0.0001$.

Table 8.2 A paired sample t-test comparing the DT scores of the variable to the fixed size approach at different eccentricities on the first and second visit

<table>
<thead>
<tr>
<th>First Visit</th>
<th>Variable size vs. Fixed size</th>
<th>Second Visit</th>
<th>Variable size vs. Fixed size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; annulus</td>
<td>$t(5) = 3.02, p = 0.03^*$</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; annulus</td>
<td>$t(5) = 2.74, p = 0.04^*$</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; annulus</td>
<td>$t(5) = 2.06, p = 0.10$</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; annulus</td>
<td>$t(5) = 0.29, p = 0.79$</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; annulus</td>
<td>$t(5) = 0.34, p = 0.75$</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; annulus</td>
<td>$t(5) = 0.69, p = 0.50$</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; annulus</td>
<td>$t(5) = -0.47, p = 0.66$</td>
<td>4&lt;sup&gt;th&lt;/sup&gt; annulus</td>
<td>$t(5) = -0.42, p = 0.69$</td>
</tr>
</tbody>
</table>

*indicates statistically significant, $p < 0.05$

A Bland-Altman test was conducted to explore if the DT with both approaches was in agreement. At the 1<sup>st</sup> annulus, the LoA ranged from -1.80 to 7.46 seconds (Figure 8.2). It was noticed that the difference increases as the mean DT lengthens, with the DT for the variable size trials being consistently longer than the fixed size trials on almost all scores. At the 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> annuli, the LoA ranged from -6.25 to 9.03, -4.75 to 5.99; and -9.31 to 7.67 seconds, respectively (Figure 8.2). At the latter three annuli, the majority of the points were scattered around the mean difference line and no clear pattern was found to indicate that one approach was always longer.
Figure 8.2 Bland-Altman test comparing the DT of both approaches at the four annuli. The dashed line is the overall mean difference, the mean differences of the four annuli, from 1st to 4th annulus are: 2.83, 1.39, 0.62 and -0.82, respectively. The LoA of the four annuli are: 7.46 to -1.80, 9.00 to -6.25, 5.99 to -4.75 and 7.67 to -9.31, respectively.

The repeatability of the DT scores collected from variable target size trials or from fixed target size trials was tested using a paired sample t-test. In variable size trials, the DT was statistically significantly different between visits at the 2nd and 4th annulus (Table 8.3). In the fixed size trials, there was no statistical significant difference between both observations at any eccentricity except at the 2nd annulus (Table 8.3).

Table 8.3 A repeatability test to compare the fixed and variable stimulus size DT at the different annuli on the two visits

<table>
<thead>
<tr>
<th>Variable size</th>
<th>first visit vs. second visit</th>
<th>Fixed size</th>
<th>first visit vs. second visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st annulus</td>
<td>( t = 1.41, p = 0.22 )</td>
<td>1st annulus</td>
<td>( t = 0.91, p = 0.41 )</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>( t = -4.20, p = 0.008^* )</td>
<td>2nd annulus</td>
<td>( t = -3.26, p = 0.02^* )</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>( t = -1.17, p = 0.30 )</td>
<td>3rd annulus</td>
<td>( t = -1.00, p = 0.36 )</td>
</tr>
<tr>
<td>4th annulus</td>
<td>( t = -2.79, p = 0.04^* )</td>
<td>4th annulus</td>
<td>( t = -0.88, p = 0.42 )</td>
</tr>
</tbody>
</table>

*indicates statistically significant, \( p < 0.05 \)
The identification accuracy of the target location (i.e. in which annulus the target was presented), and direction with both methods varied only slightly with eccentricity (Table 8.4). Identifying the target location was to some extent better in the variable size trials in comparison to the scores in the fixed size trials (Table 8.4), but identifying the target direction was near to 100% in both approaches of target size. The Chi-square test for independence showed, on both visits, that there was no significant association between the method used to adjust the target size and the accuracy of detecting the target location and direction (Table 8.5). Further, the Chi-square test showed that on the first and second visit no significant association was found between the eccentricity and the accuracy of detecting the target location and target direction in either target sizes (Table 8.6). No significant association was found between the visits as a factor in the accuracy of detecting the target locations in both variable and fixed target size trials ($\chi^2 (1, n=368) = 0, p = 1.00$) showing that there was no improvement in performance on the second visit.
Table 8.4 The percentage accuracy of the reporting of position and direction

<table>
<thead>
<tr>
<th>Target Location</th>
<th>Variable first visit</th>
<th>Variable second visit</th>
<th>Fixed first visit</th>
<th>Fixed second visit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1\textsuperscript{st} Annulus</td>
<td>1\textsuperscript{st} Annulus</td>
<td>1\textsuperscript{st} Annulus</td>
<td>1\textsuperscript{st} Annulus</td>
</tr>
<tr>
<td>Position Accuracy</td>
<td>98%</td>
<td>98%</td>
<td>92%</td>
<td>91%</td>
</tr>
<tr>
<td>Direction accuracy</td>
<td>100%</td>
<td>98%</td>
<td>100%</td>
<td>98%</td>
</tr>
<tr>
<td>Target Location</td>
<td>2\textsuperscript{nd} Annulus</td>
<td>2\textsuperscript{nd} Annulus</td>
<td>2\textsuperscript{nd} Annulus</td>
<td>2\textsuperscript{nd} Annulus</td>
</tr>
<tr>
<td>Position Accuracy</td>
<td>88%</td>
<td>85%</td>
<td>84%</td>
<td>84%</td>
</tr>
<tr>
<td>Direction accuracy</td>
<td>98%</td>
<td>98%</td>
<td>99%</td>
<td>98%</td>
</tr>
<tr>
<td>Target Location</td>
<td>3\textsuperscript{rd} annulus</td>
<td>3\textsuperscript{rd} annulus</td>
<td>3\textsuperscript{rd} annulus</td>
<td>3\textsuperscript{rd} annulus</td>
</tr>
<tr>
<td>Position Accuracy</td>
<td>92%</td>
<td>91%</td>
<td>85%</td>
<td>85%</td>
</tr>
<tr>
<td>Direction accuracy</td>
<td>100%</td>
<td>100%</td>
<td>98%</td>
<td>99%</td>
</tr>
<tr>
<td>Target Location</td>
<td>4\textsuperscript{th} annulus</td>
<td>4\textsuperscript{th} annulus</td>
<td>4\textsuperscript{th} annulus</td>
<td>4\textsuperscript{th} annulus</td>
</tr>
<tr>
<td>Position Accuracy</td>
<td>94%</td>
<td>94%</td>
<td>85%</td>
<td>92%</td>
</tr>
<tr>
<td>Direction accuracy</td>
<td>98%</td>
<td>98%</td>
<td>98%</td>
<td>98%</td>
</tr>
</tbody>
</table>

Table 8.5 The Chi-square result of the impact of the target size on both accuracy measures

<table>
<thead>
<tr>
<th></th>
<th>First visit</th>
<th></th>
<th>Second visit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy of Location</td>
<td>( \chi^2 ) (1, n=368) = 3.32, ( p = 0.07 )</td>
<td></td>
<td>( \chi^2 ) (1, n=368) = 3.32, ( p = 0.07 )</td>
<td></td>
</tr>
<tr>
<td>Accuracy of Direction</td>
<td>( \chi^2 ) (1, n=368) = 0.202, ( p = 0.15 )</td>
<td></td>
<td>( \chi^2 ) (1, n=368) = 0.202, ( p = 0.15 )</td>
<td></td>
</tr>
</tbody>
</table>

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Table 8.6 The Chi-square result of the impact of the target eccentricity on both accuracy measures

<table>
<thead>
<tr>
<th></th>
<th>First visit Variable target size</th>
<th>First visit Fixed target size</th>
<th>Second visit Variable target size</th>
<th>Second visit Fixed target size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy of Location</td>
<td>$\chi^2 (3, n=184) = 5.49, p = 0.14$</td>
<td>$\chi^2 (3, n=184) = 1.62, p = 0.65$</td>
<td>$\chi^2 (3, n=184) = 1.98, p = 0.58$</td>
<td>$\chi^2 (3, n=184) = 0.57, p = 0.90$</td>
</tr>
<tr>
<td>Accuracy of Direction</td>
<td>$\chi^2 (3, n=184) = 5.49, p = 0.14$</td>
<td>$\chi^2 (3, n=184) = 2.19, p = 0.53$</td>
<td>$\chi^2 (3, n=184) = 2.19, p = 0.53$</td>
<td>$\chi^2 (3, n=184) = 0.57, p = 0.90$</td>
</tr>
</tbody>
</table>
8.2.3 General Discussion

The main aim of this study was to determine which approach to adopt in terms of the change in target size with eccentricity in the AVA test. The DT at the 1st annulus was significantly faster with the fixed size suggesting that the size used was so large that the participant did not need to actively scan to locate the target (Table 8.1). This would mean that the DT recorded at the 1st annulus with the fixed size is a simple reaction time, reflecting the individual’s ability to press the button. On the other hand, with the variable size, the increased DT at the 1st annulus suggests that the participant was required to scan the area to identify the targets.

The planned comparison of the DT with both methods showed that there were no statistically significant differences between the two approaches except the DT at the 1st annulus as discussed above (Table 8.2). Further, the ANOVA showed that the target location influenced the DT regardless of the target size that was used, with the DT scores getting progressively longer as the target moved toward more peripheral locations. This result indicates that the sensitivity of the test was not impacted by the change in the target size. This supports the hypothesis that not using the cortical magnification factor does not affect the participants’ DT or the sensitivity of the AVA test, suggesting that detection occurs in the central retinal area.

The Bland-Altman plot shows that the two approaches are in agreement at the three more peripheral locations as the data are scattered symmetrically around the zero mean difference. This result suggests that neither approach to determining the target size gave DT scores that were always faster or always slower. However, the DT at the 1st annulus in the Bland-Altman plot were longer with the variable size target, suggesting that at this point both methods were not in agreement. Overall, this result suggests that either target size approach adopted for the awareness test would have little effect on the AVA test scores.
Interestingly, the vast majority of the DT scores recorded at the four annuli on the second visit were longer than the DT scores on the first visit. The repeatability of the DT scores was conducted with each method. With the variable size, a significant difference between the visits was found in the DT scores at the 2\textsuperscript{nd} and 4\textsuperscript{th} annulus. With the fixed size, no significant difference was found between the two visits except at the 2\textsuperscript{nd} annulus (Table 8.3). However, as these scores indicate that the participant was slower at the second visit, this would exclude any learning effect. This result could be considered as supportive evidence that in order to improve the DT scores significantly an effective intervention needs to be introduced: this was the aim of designing the AVA test in the first place.

The accuracy of identifying the target location did appear to be better in the variable size trials, which was predicted. However, this difference in scores was not found to be statistically significant. Further the accuracy of identifying the target direction was very high and was not statistically significantly different between both approaches. This latter result was expected as the size change gave no indication of the target direction. Neither the target location nor the number of visits were found to have a significant effect on the two accuracy measures. This result also was expected as the percentage accuracy for identifying the target location and direction was 90\% or more.

In summary, we found statistical evidence to show that there is a difference between the two approaches at the 1\textsuperscript{st} annulus with no impact of the target size on the DT at the rest of the annuli. This could indicate that adopting either approach would not invalidate the AVA test design. The accuracy of identifying the target location was to some extent better in the variable target size than the fixed target size. This means that using the variable target sizes may potentially provide the participants with clues about the target location Therefore, in the main AVA test design the recommendation is to use the small target size (0.50°) at the 1\textsuperscript{st}
annulus because it will be then need to be scanned for; and at the rest of the annuli, to use the target size of 1° in order to avoid the potential of providing the participant with clues about the target location.

8.3 Background Selection

The aim of this experiment was to find out the best choice of background for use in the AVA test. Three backgrounds were compared to test DT in each case: a street scene photograph, a spatial noise background and a uniform gray background.

The street scene background is complex and represents the real environment that the participants are familiar with and usually move about in. However, such a scene consists of large areas of varying luminance and distracting objects which could markedly influence the difficulty level of the task for some target locations. Twelve colour photographs that illustrate real landscapes were taken, for this purpose, in the city centre of Manchester. The chosen backgrounds represent typical situations that require mobility and contain potential obstacles to the sides in several directions. One photograph out of the twelve was selected for the experiment, which was a normal traffic intersection containing distracters such as cars, pedestrians, traffic signs, buildings, and signs attached to the buildings (Figure 8.3).

The photograph was cropped from the top in order to centralise the fixation target at the street level, and to enable division of the background into four equal quadrants to allow annuli comparison. The test was carried out in a dimly lit room, therefore the background luminances were measured under that condition. The luminance of the background varied markedly and ranged from 8 to 60 cd/m². For instance, the luminance at the top of the background (sky) was 60 cd/m², whereas it was approximately 12 cd/m² at the top right (periphery at the 1.30 meridian) and 9 cd/m² at bottom part (periphery at the 7.30 meridian) (Figure 8.3).
The visual noise background, defined as "any stimulus that reduces the visibility of a target when superimposed on it" (Pardhan et al., 1993), was taken into account. Visual noise can also be defined as random fluctuations in luminance over space and time, or both (Radhakrishnan and Pardhan, 2006). The noise is described based on its dimensions of spatial variation into one or two dimensions (Pardhan et al., 1993). The noise that randomly fluctuates over time is called "dynamic" noise; the noise that does not is called "static" noise (Pardhan et al., 1993). Two dimensional static noise is of the type in an old photograph whereas two dimensional dynamic noise resembles a TV monitor (Pardhan et al., 1993). The noise background that was considered in this project was 1/f spatial noise: two dimensional static noise on which the targets will be superimposed.

The idea of using the spatial noise (1/f) background in our study was based on the fact that natural scenes have relatively consistent statistical features (Field, 1987). The radial average amplitude spectrum is fairly consistent across natural images (Geisler, 2008). Specifically, the 1/f^n noise background (where n is approximately 1 yet varies between 0.8 and 1.5 (Tolhurst et al., 1992)) has been widely accepted as it has the same statistical and spatial frequency features that are found in natural scenes, yet there are no distinguishable objects, edges or contours. The noise background would provide a uniform background across the
display. Using the 1/f noise could eliminate most of the disadvantages of real-world pictures, yet would increase the target masking and the difficulty of the task in comparison to a blank background. In this study the n value was set at 1 as suggested by Tolhurst et al. (1992). The mean luminance of the 1/f noise background was 22 cd/m². The luminance was almost equal at the different parts of the display (the variation ranged ± 2 cd/m²) (Figure 8.4).

Figure 8.4 The 32 targets on the noise background scene are shown with the red cross in the centre. The 8 targets at the 1st annulus may not be as clear as the rest of the targets. This is because the target are smaller than the rest of the targets and because the photo was taken at approximately 2 meters in order to capture all the 32 targets.

A blank uniform gray background was also used in this study to explore the difference in performance between it and the other backgrounds. The mean luminance of the gray background was 24 cd/m². The luminance varied by ±2 cd/m² across the display.

We hypothesize that the DT using the photographic background would vary in accordance with the target's position, i.e. whether it appears in a low or high luminance area. However, this would not be found with either the noise or the gray backgrounds. Further, the DT with
the noise background might be longer than the DT with the gray background, because the noise background is more complex.

8.3.1 Materials and Methods

Twenty five participants (9 male and 16 female) with normal visual performance were recruited from University of Manchester students and staff. One participant withdrew from the study because she was tired and not able to complete the test sets, therefore, her data were removed from the analysis. The TV was simulated using the method described earlier (Chapter 5, section 5.3). It was decided to simulate two out of the four FoV sizes and to present the targets at two out of the four locations in order to reduce time taken, minimize subject fatigue and also to enable us to test the participants with and without VA and CS loss, which was simulated using a Bangerter foil (Haag-Streit, UK). This was chosen to match the anticipated VA and CS of real TV patients. The two FoV sizes used in this experiment were 20° and 5° i.e. the maximum and minimum FoV sizes. The targets were presented at two different annuli: at the 2nd annulus (at 10° radius from the central cross) and the 3rd annulus (at 20° radius from the central cross). These two location were chosen as the 2nd annulus is more peripheral than the 1st annulus and requires more scanning, and the 4th annulus is presented towards the edge of the screen and may not have distracters. The three backgrounds were presented in a random order, and the test was repeated four times. The four sets were: FoV of 20° without simulated visual function loss, FoV of 20° with visual function loss, FoV of 5° without any visual function loss, and FoV of 5° with visual function loss, and this is the order in which the tests were performed. This order was chosen as it allowed the participants to become progressively familiar with the experience of visual loss.

The participants’ VA was measured with the logMAR VA ETDRS chart "2000" (Precision Vision, La Salle IL 61301, US). The CS was measured with the Pelli-Robson CS chart at one
metre with overhead illumination (approximately 85 cd/m²) (Metropia Ltd., UK; distributed by Clement Clarke Intl) (Pelli et al., 1988). The VF test was done for every participant and with each simulator before doing the AVA test. The VF was measured using the Bjerrum screen and the method used to calculate the VF size is described in Chapter 5, section 5.3.2. All participants satisfied the inclusion criteria (Chapter 5, section 5.3.1). All participants used their habitual correction if they had one.

8.3.2 Results

The participants’ age was 21.50 ± 2.75 years (Mean ± SD); ranging from 18 to 29 years. The participants’ VA in the RE was -0.12 ± 0.10 logMAR; ranging from -0.34 to 0.10 logMAR. The VA with Bangerter foil was reduced to 0.39 ± 0.10 logMAR; ranging from 0.20 to 0.60. The CS in the RE was 1.75 ± 0.10 log CS; ranging from 1.60 to 1.90 log CS. The CS with Bangerter foil had declined to 1.25 ± 0.10 log CS; ranging from 1.05 to 1.35 log CS. The simulated FoV sizes of the two simulators for the 24 participants were: 20°± 0.90°, range 18° to 21° and 5.00°±0.50°, range 4° to 6°; respectively.

The scores collected from the AVA test were tested for normality. The Kolmogorov-Smirnov test showed that the data were not normally distributed (p < 0.05), therefore non-parametric tests were used.

Two methods were used to investigate the effect of the different backgrounds on the DT scores. The first method explored the impact of the background on the DT scores, where the DT was the median DT of the eight target locations presented at each eccentricity, as has been previously described in this chapter (section 8.1) and used in the target size study. A new method of calculating the DT was also used in this particular study in order to take into account the luminance variation in the photographic background. Specifically, the differences in DT scores between the upper part of the background, which had high luminance (about 60
cd/m^2), and the lower part of the background, which had low luminance (about 10 cd/m^2), were compared. The DT scores for the three backgrounds were therefore divided into two sets of scores: one representing the upper part of the background (on the clock: 10.30, 12.00 and 1.30), and the second representing the lower part (on the clock: 4.30, 6.00 and 7.30). The median DT of the three target locations presented in the upper part of the background for each participant at each annulus was named the UDT and that in the lower part the LDT. The targets presented at 3 o'clock and 9 o'clock were removed from this analysis. Investigating the effect of the background using the DT, UDT and LDT scores meant that we could use the same data twice to explore the two hypotheses. Therefore, the Bonferroni correction was applied here and the p value was set to be 0.025.

The DT scores with three different backgrounds and with or without the simulated defect in SIPs 20\degree and SIPs 5\degree are listed in Table 8.7. Briefly, in SIPs 20\degree at the 2\textsuperscript{nd} annulus there was a minimal change in DT scores between the three backgrounds. Conversely, at the 3\textsuperscript{rd} annulus there was a two-fold difference in DT between the noise and the photographic background, yet no marked difference was found between the DT in the noise and gray backgrounds. In SIPs 5\degree, the DT scores with the photographic background were about double the time needed to respond with the noise background either at the 2\textsuperscript{nd} or 3\textsuperscript{rd} annulus. The DTs recorded at the 2\textsuperscript{nd} and 3\textsuperscript{rd} annulus were not markedly different between the noise and the gray backgrounds.

When the simulated VA/CS limitation was considered, in SIPs 20\degree at the 2\textsuperscript{nd} annulus there was a minimal change in DT where the slowest DT was with the photographic background. At the 3\textsuperscript{rd} annulus the DT with the photographic background was twice as long as the DT with the other two backgrounds. In SIPs 5\degree with the simulated defect, the DT was markedly longer with the photographic background at both locations than the DT with the noise background. Using the noise background, the DT at both locations was longer than with the gray background.
Table 8.7 The Median ± IQR of the DT scores with both FoV sizes and with/out the Bangerter foil

<table>
<thead>
<tr>
<th>Target Location</th>
<th>SIPs 20° Without</th>
<th>SIPs 20° With</th>
<th>SIPs 5° Without</th>
<th>SIPs 5° With</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
</tr>
<tr>
<td>2nd Annulus Noise</td>
<td>1.10 ± 0.45</td>
<td>1.10 ± 0.62</td>
<td>5.99 ± 3.62</td>
<td>8.24 ± 4.12</td>
</tr>
<tr>
<td>2nd Annulus Photo</td>
<td>1.15 ± 0.69</td>
<td>1.59 ± 0.82</td>
<td>11.08 ± 7.99</td>
<td>16.78 ± 13.43</td>
</tr>
<tr>
<td>2nd Annulus Gray</td>
<td>1.13 ± 0.56</td>
<td>0.94 ± 0.62</td>
<td>6.13 ± 3.22</td>
<td>6.81 ± 4.93</td>
</tr>
<tr>
<td>3rd Annulus Noise</td>
<td>2.70 ± 0.95</td>
<td>3.25 ± 1.46</td>
<td>7.86 ± 7.16</td>
<td>11.21 ± 4.57</td>
</tr>
<tr>
<td>3rd Annulus Photo</td>
<td>4.71 ± 3.41</td>
<td>7.22 ± 5.94</td>
<td>14.86 ± 9.40</td>
<td>17.02 ± 13.21</td>
</tr>
<tr>
<td>3rd Annulus Gray</td>
<td>2.34 ± 1.46</td>
<td>3.23 ± 1.99</td>
<td>9.33 ± 6.42</td>
<td>9.98 ± 5.70</td>
</tr>
</tbody>
</table>

The Friedman test was performed to investigate the dependence of the DT on the background in SIPs 20° and SIPs 5° with/out using the simulated defect. There was a statistically significant difference in DT across the three backgrounds either with or without the simulated defect in the two FoV sizes and at both target locations (Table 8.8).

Table 8.8 Friedman test exploring the impact of different backgrounds on the DT with and without the simulated defect

<table>
<thead>
<tr>
<th>Target Location</th>
<th>SIPS 20°</th>
<th>SIPS 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd annulus without</td>
<td>$X^2 (2, n=24) = 36.00, p &lt; 0.0001^*$</td>
<td>$X^2 (2, n=24) = 16.75, p &lt; 0.0001^*$</td>
</tr>
<tr>
<td>2nd annulus without</td>
<td>$X^2 (2, n=24) = 30.58, p &lt; 0.0001^*$</td>
<td>$X^2 (2, n=24) = 30.25, p &lt; 0.0001^*$</td>
</tr>
<tr>
<td>2nd annulus with</td>
<td>$X^2 (2, n=24) = 12.25, p = 0.002^*$</td>
<td>$X^2 (2, n=24) = 16.33, p &lt; 0.0001^*$</td>
</tr>
<tr>
<td>2nd annulus with</td>
<td>$X^2 (2, n=24) = 36.10, p &lt; 0.0001^*$</td>
<td>$X^2 (2, n=24) = 22.33, p &lt; 0.0001^*$</td>
</tr>
</tbody>
</table>

* indicates statistical significance, $p < 0.025$

A Wilcoxon signed rank test was performed in SIPs 20° and SIPs 5° to compare the DT scores between: 1) the noise and the photographic background and 2) between the noise and gray background, at the two target locations and with/out the simulated defect (Table 8.9). It
was found that there was a statistically significant difference in DT scores between the noise and the photographic background with the two FoV sizes and either with or without the simulated defect, except at the 2nd annulus in SIPs 20° (Table 8.9). No significant difference was found between the gray and noise backgrounds at any location or under any condition (Table 8.9).
Table 8.9 Wilcoxon signed rank test comparing the DT scores with different background

<table>
<thead>
<tr>
<th></th>
<th>SIPs 20° Without</th>
<th>SIPs 20° With</th>
<th>SIPs 5° Without</th>
<th>SIPs 5° With</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2nd Annulus</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise vs. photo</td>
<td>( Z = -2.10 / p = 0.04 )</td>
<td>( Z = -2.71 / p = 0.007^* )</td>
<td>( Z = -3.46 / p = 0.001^* )</td>
<td>( Z = -3.71 / p &lt; 0.0001^* )</td>
</tr>
<tr>
<td>Gray vs. Noise</td>
<td>( Z = -0.37 / p = 0.71 )</td>
<td>( Z = -2.09 / p = 0.04 )</td>
<td>( Z = -0.34 / p = 0.73 )</td>
<td>( Z = -0.74 / p = 0.46 )</td>
</tr>
<tr>
<td><strong>3rd Annulus</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise vs. photo</td>
<td>( Z = -4.23 / p &lt; 0.0001^* )</td>
<td>( Z = -4.29 / p &lt; 0.0001^* )</td>
<td>( Z = -4.11 / p &lt; 0.0001^* )</td>
<td>( Z = -3.09 / p = 0.002^* )</td>
</tr>
<tr>
<td>Gray vs. Noise</td>
<td>( Z = -1.09 / p = 0.28 )</td>
<td>( Z = -0.71 / p = 0.48 )</td>
<td>( Z = -0.66 / p = 0.51 )</td>
<td>( Z = -1.51 / p = 0.13 )</td>
</tr>
</tbody>
</table>

* indicates statistical significance, \( p < 0.025 \)
A Wilcoxon test was performed to investigate the effect of the simulated defect on the DT scores with each background in both SIPs 20° and SIPs 5° (Table 8.10). In SIPs 20°, the DT scores were not found to be different at the 2nd annulus, whereas they were significantly different at the 3rd annulus in the three backgrounds. In SIPs 5°, the DT scores were found to be significantly different at the 2nd annulus for the three backgrounds, but at the 3rd annulus only the DT scores in the noise background were found to be significantly different.

Table 8.10 Wilcoxon Signed Ranks Test comparing the DT scores with/out the simulated defect

<table>
<thead>
<tr>
<th>Target Location</th>
<th>Noise</th>
<th>Gray</th>
<th>Photographic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SIPs 20° With vs. without</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Annulus</td>
<td>Z = -0.23, p = 0.82</td>
<td>Z = -0.71, p = 0.48</td>
<td>Z = -1.60, p = 0.11</td>
</tr>
<tr>
<td>3rd Annulus</td>
<td>Z = -2.51, p = 0.012*</td>
<td>Z = -3.00, p = 0.003*</td>
<td>Z = -2.94, p = 0.003*</td>
</tr>
<tr>
<td><strong>SIPs 5° With vs. without</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Annulus</td>
<td>Z = -2.91, p = 0.004*</td>
<td>Z = -2.46, p = 0.014*</td>
<td>Z = -2.74, p = 0.006*</td>
</tr>
<tr>
<td>3rd Annulus</td>
<td>Z = -2.51, p = 0.012*</td>
<td>Z = -1.05, p = 0.30</td>
<td>Z = -1.77, p = 0.08</td>
</tr>
</tbody>
</table>

* indicates statistical significance, p < 0.025

Considering the DT scores in the upper and lower parts of the background, there were minimal differences between the UDT and LDT with the noise and gray backgrounds either with or without the simulated defect. The differences between these scores were about one second or less (Table 8.11). For example, with the noise background, in the SIPs 20° without, at the 3rd annulus, the difference between UDT and LDT was about 0.70 seconds. Further, in the gray background, in the SIPs 5° with, at the 2nd annulus, the difference between UDT and LDT was about 0.80 seconds. In contrast, for the photographic background the differences between UDT and LDT scores were obvious and the UDT were, in most cases, about twice as long, both with/out the simulated defect (Table 8.11). For example, the UDT and LDT, at the 3rd annulus in the SIPs 20° with foil, were 10.27 and 5.30, respectively.
Table 8.11 The Median ± IQR of the DT scores with both FoV sizes and with/out the Bangerter foil

<table>
<thead>
<tr>
<th>Target Location</th>
<th>SIPs 20° Without</th>
<th>SIPs 20° With</th>
<th>SIPs 5° Without</th>
<th>SIPs 5° With</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise Background</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
</tr>
<tr>
<td>2nd Annulus UDT</td>
<td>1.18 ± 0.63</td>
<td>1.22 ± 0.57</td>
<td>5.23 ± 7.67</td>
<td>10.78 ± 6.94</td>
</tr>
<tr>
<td>2nd Annulus LDT</td>
<td>1.09 ± 0.64</td>
<td>0.99 ± 0.71</td>
<td>8.75 ± 7.27</td>
<td>9.74 ± 9.80</td>
</tr>
<tr>
<td>3rd Annulus UDT</td>
<td>2.40 ± 1.62</td>
<td>2.64 ± 1.40</td>
<td>9.04 ± 9.70</td>
<td>11.22 ± 7.81</td>
</tr>
<tr>
<td>3rd Annulus LDT</td>
<td>3.16 ± 1.25</td>
<td>3.91 ± 1.98</td>
<td>9.71 ± 7.98</td>
<td>11.85 ± 9.37</td>
</tr>
<tr>
<td>Photo Background</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
</tr>
<tr>
<td>2nd Annulus UDT</td>
<td>1.92 ± 3.45</td>
<td>2.07 ± 3.05</td>
<td>14.48 ± 20.55</td>
<td>25.83 ± 23.07</td>
</tr>
<tr>
<td>2nd Annulus LDT</td>
<td>1.16 ± 0.61</td>
<td>1.37 ± 0.80</td>
<td>7.90 ± 8.66</td>
<td>13.84 ± 16.18</td>
</tr>
<tr>
<td>3rd Annulus UDT</td>
<td>5.68 ± 4.29</td>
<td>10.27 ± 8.38</td>
<td>15.09 ± 10.29</td>
<td>21.77 ± 22.17</td>
</tr>
<tr>
<td>3rd Annulus LDT</td>
<td>3.64 ± 2.97</td>
<td>5.30 ± 4.36</td>
<td>13.97 ± 12.40</td>
<td>17.60 ± 16.27</td>
</tr>
<tr>
<td>Gray Background</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
<td>Md. ± IQR</td>
</tr>
<tr>
<td>2nd Annulus UDT</td>
<td>1.06 ± 0.62</td>
<td>1.14 ± 0.77</td>
<td>5.73 ± 6.51</td>
<td>7.44 ± 8.96</td>
</tr>
<tr>
<td>2nd Annulus LDT</td>
<td>1.06 ± 0.56</td>
<td>0.98 ± 0.58</td>
<td>6.59 ± 6.25</td>
<td>8.22 ± 10.17</td>
</tr>
<tr>
<td>3rd Annulus UDT</td>
<td>2.48 ± 1.68</td>
<td>3.53 ± 2.58</td>
<td>10.02 ± 9.08</td>
<td>11.48 ± 9.10</td>
</tr>
<tr>
<td>3rd Annulus LDT</td>
<td>2.35 ± 2.11</td>
<td>3.10 ± 1.58</td>
<td>9.42 ± 7.52</td>
<td>11.26 ± 10.16</td>
</tr>
</tbody>
</table>

A Wilcoxon test was conducted to investigate if the differences between the UDT and LDT were statistically significant. In the photographic background there was significant difference between the UDT and LDT on most occasions at the 2nd annulus, except in SIPs 20° with the defect. At the 3rd annulus there was significant difference between the UDT and LDT in SIPs 20°, but not in SIPs 5° (Table 8.12). With the noise background, no statistically significant difference was found either with or without the simulated defect except on one occasion, with FoV of 20° with the simulated defect at the 3rd annulus (Table 8.12). In the gray background, there were statistically significant differences between the UDT and LDT on one occasion, in a SIP 20° with simulated defect (Table 8.12).
Table 8.12 Wilcoxon Test comparing the UDT and LDT

<table>
<thead>
<tr>
<th>Background</th>
<th>SIPS 20° Without</th>
<th>SIPS 20° With</th>
<th>SIPS 5° Without</th>
<th>SIPS 5° With</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2nd Annulus UDT vs. LDT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td>$Z = -0.17, p = 0.86$</td>
<td>$Z = -0.06, p = 0.95$</td>
<td>$Z = -1.20, p = 0.23$</td>
<td>$Z = -1.03, p = 0.30$</td>
</tr>
<tr>
<td>photographic</td>
<td>$Z = -3.14, p = 0.002^*$</td>
<td>$Z = -2.14, p = 0.032$</td>
<td>$Z = -2.71, p = 0.007^*$</td>
<td>$Z = -3.06, p = 0.002^*$</td>
</tr>
<tr>
<td>Gray</td>
<td>$Z = -0.46, p = 0.65$</td>
<td>$Z = -2.31, p = 0.021^*$</td>
<td>$Z = -0.60, p = 0.55$</td>
<td>$Z = -1.13, p = 0.26$</td>
</tr>
<tr>
<td></td>
<td>3rd Annulus UDT vs. LDT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td>$Z = -1.51, p = 0.13$</td>
<td>$Z = -2.26, p = 0.024^*$</td>
<td>$Z = -0.94, p = 0.35$</td>
<td>$Z = -1.69, p = 0.09$</td>
</tr>
<tr>
<td>photo</td>
<td>$Z = -2.94, p = 0.003^*$</td>
<td>$Z = -2.55, p = 0.011^*$</td>
<td>$Z = -0.20, p = 0.84$</td>
<td>$Z = -2.10, p = 0.04$</td>
</tr>
<tr>
<td>Gray</td>
<td>$Z = -0.09, p = 0.93$</td>
<td>$Z = -0.46, p = 0.65$</td>
<td>$Z = -2.00, p = 0.046$</td>
<td>$Z = -0.88, p = 0.38$</td>
</tr>
</tbody>
</table>

* indicates statistical significance, $p < 0.025$
8.3.3 General Discussion

In this study three different backgrounds were compared in order to find the best choice for the AVA test background. The change in background was found to impact the DT scores, as they were markedly longer with the photographic background (Table 8.7). Further, the DT scores were more variable with the photographic background. This could be because of the luminance variation, as much longer DTs were recorded in the upper (bright) part of the field, compared to the lower. This difference in DT in different areas was not evident on the other backgrounds.

The simulated defect (VA and CS limitation) also influenced DT scores, and the extent was dependent on the target location and the test background (Tables 8.7 and 8.10). Generally, the DT scores were longer with the simulated defect (Table 8.7). However, no significant difference was found in SIPS 20° at the 2nd annulus with all three backgrounds (Table 8.10). This could be because the target was always available within the simulated FoV and therefore was not found to be significantly different. However, when the target was presented at more peripheral locations outside the simulated FoV which require more active scanning, a significant difference was found. This explanation is supported by the 2nd annulus scores in SIPS 5°, where this location was presented outside the functioning area and was found to be impacted by simulated defect. In SIPS 5°, no significant difference was found between with and without the defect at the 3rd annulus in both the gray and the photographic background. This is could be accounted for by the fact that the DT scores were highly variable.

The DT scores were divided into UDT and LDT and were compared. Generally, it can be seen that the DT scores were slower in the upper part of the background in the photographic background (Table 8.7). This result suggests that the area with high luminance (upper part) caused a delay in the DT. This suggestion was, generally, supported by the Wilcoxon test.
results (Table 8.12), where the DT scores in the photographic background were found to be significantly different between the upper and lower part at the 2\textsuperscript{nd} annulus in both FoV sizes and at the 3\textsuperscript{rd} annulus in SIPs 20°. However, the UDT and LDT at the 3\textsuperscript{rd} annulus in SIPs 5° was not significantly different. This is seems to be due to the high variation in UDT and LDT scores. In the gray background it was found that there was one occasion where there was significant difference between UDT and LDT. The difference in scores was minimal but there were no obvious reasons for the significant difference. Further, no significant difference was found in the noise at the 2\textsuperscript{nd} annulus and only in one occasion at the 3\textsuperscript{rd} annulus with the defect, which could be the reason for the significant difference. Generally it seems that the noise background provided a uniform background.

The DT scores between the noise and the gray background were not found to be significantly different. And generally, no difference in DT scores was found between the upper and lower part in either case, confirming that both would provide a uniform background. Further, DTs with both backgrounds responded equally to the change in VA/CS level (Table 8.10), but were markedly less impacted than the photographic background. Based on these results, it was decided that the noise background was an appropriate choice for the AVA test, as the 1/f noise would be representative of the natural environment without the complication of the variation in contrast that can be found in real scenes. The noise background in its different forms has been used previously in assessing the CS in patients with cataracts (Pardhan et al., 1993), assessing contrast detection in myopic patients (Radhakrishnan and Pardhan, 2006) and to evaluate stimuli detection in the ring scotoma of a monocular bioptic telescope (Doherty et al., 2011).
8.4 The AVA Test Design Summary

Peripheral targets will be presented in 32 different locations, evenly distributed over the main eight radii at four different eccentricities. The eccentricities will be at 5°, 10°, 20°, and 30° from the centre of the display. The target will be a black-and-white square in order to provide maximum contrast. The size of the target will be 0.50° at the 1st annulus (to encourage scanning) and 1° at the rest of the locations. The peripheral targets will be presented in a random order for an unlimited period of time. A central target will also be presented on the same display and will be a cross, with an overall arm length of 70 mm (3°), in red or blue, and orientation (+ or ×) to be identified by the participant. The combination of the two targets will be used to ensure that the participant scan across the field, to avoid their finding the target by chance. The peripheral targets will be presented with a Weber contrast of 0.60 for the upper part (white) and 0.45 for the lower part (black). The central targets will be presented with a Weber contrast of 0.45 for both target colours (red and blue). The displays will be presented using a digital projector (CP-AW100N, Hitachi, UK). The image is processed at a 100 Hz frame rate and projected onto a 200 ×150 cm opaque screen. The participant will sit at a distance of 1.20m from the screen and the presentation area will be 81° H × 62° V.

Prior to the test, each participant will be given a brief demonstration. Participants will be informed that head and eye movements are permitted. Participants will be asked to search for and locate the peripheral target, which could be anywhere within the background. Participants will be asked to press the response key upon detection of both the targets, and the DT will be recorded automatically and sent to an Excel spreadsheet. They will then be asked to verbally identify the central target (by colour and/or orientation) and the location of the peripheral target (by clock position and annulus). The score collected will include the accuracy of the
target location; if the target location is deemed inaccurate (i.e. not in the same quadrant) or if the participant inaccurately reports the central target, then the DT will be omitted from further analysis.
Chapter Nine: The Performance of Subjects with Real and Simulated Tunnel Vision in the AVA Test


9.1 Aims and Hypothesis

The sensitivity and validity of the Assessment of Visual Awareness (AVA) test will be investigated in SIPs, TVPs and hemianopic patients. Highly significant relationships are expected between the DT scores and the FoV, and these will be influenced by the target location. The repeatability of the AVA test will be studied only in the SIPs in order to investigate the possible effect of a learning factor. The AVA test is expected to be repeatable and not vary significantly between visits. Further, the relationship between the TVPs’ visual functions (i.e. VA and CS) and the DT scores will be tested. The DT scores are not expected to have a significant relationship with the participants' visual functions as the target used here was selected to be well above the threshold of the recruited participants' VA and CS. This relationship will be explored only in TVPs: the SIPs visual functions are not expected to have a relationship with the DT scores, because the SIPs are a homogeneous group of young people with good VA and CS. The relationship between the TVPs reported outcome and the DT scores will also be investigated: a significant relationship is expected with the IMQ questionnaire, and with the domain of the LVQOL questionnaire that relates to mobility (but not with the other domains). The difference in performance between the SIPs and TVPs will be investigated. The TVPs are expected to have shorter DT than the SIPs, as the TVPs are well adapted to the condition and perform the AVA test binocularly. The relationship between the DT scores, in both SIPs and TVPs, and the mobility scores will be investigated. A significant relationship is expected between the DT scores and the mobility scores in both groups, and this could provide evidence of the validity of the AVA test.

In order to assess the usability of the AVA test in another group with VF defects, the performance of hemianopic patients will also be investigated. The DT scores in this group are expected to be faster on one side of the display and slower on the other side. This is because the targets on one side will fall on the functioning part of the VF and the targets on the other
side will fall on the non-functioning part of the VF. This outcome may provide further evidence that the AVA test responses are determined by the extent of the FoV.

9.2 Materials and Methods

The AVA design and scores summarised in the previous chapter (Chapter 8, section 8.4) were used in this study. The method of simulating TV in the SIPs, as described above, was used in this study (Chapter 5, section 5.3). The participants were recruited using announcements via the University system, invitations sent to RP Facebook groups and invitations handed to patients visiting the LV clinic in the University of Manchester. The participants were 50 SIPs (28 male and 22 female); 20 TVPs (9 males and 11 females) and two patients with hemianopia caused by stroke (both male). All the SIPs were tested on two visits with a gap of one to two weeks between them. The SIPs were tested in their monocular state (RE), as described earlier and the TVPs and the patients with hemianopia were tested in their habitual state of binocular vision. The hemianopic patients visited our lab once and performed the AVA test, but not the mobility course as the stroke had caused physical limitations when walking. The same standardized description and instructions for the AVA test were read to all participants (Appendix One).

The participants’ VA was measured with logMAR VA ETDRS chart "2000" (Precision Vision, La Salle IL 61301, US). The CS was measured with the Pelli-Robson CS chart at one metre with overhead illumination (approximately 85 cd/m²) (Metropia Ltd in UK; distributed by Clement Clarke Intl) (Pelli et al., 1988). The VF test was done for all participants, with each simulator in the SIPs group, before doing the AVA test on each visit. The VF, in the SIPs and TVPs, was measured using the Bjerrum screen and the VF size was calculated as described earlier (Chapter 5, section 5.3.2). The hemianopic patients’ VF was assessed using the binocular Esterman test and run on the Humphrey VF Analyzer (Carl Zeiss Meditec Inc.;
USA). All participants satisfied the inclusion criteria (Chapter 5, section 5.3.1). Participants used their habitual correction (if they had one).

### 9.3 Participants' Visual Functions Result

In SIPs, no signs of amblyopia were found, and full correction (if required) of the participants' refractive error was incorporated in the trial frame for each individual. The spherical equivalent (SE) refraction in the RE was: -0.75 ± 1.50 DS (means ± SD) (ranging from -5.50 DS to + 3.75 DS). The TVP means ± SD of the SE refraction in the RE was: -1.50 ± 2.50 DS (ranging from -8.75 DS to +2.00 DS) and in the LE was: -1.50 ± 2.50 DS (ranging from -7.50 DS to + 4.00 DS). The hemianopic patients' SE refractions in the RE were: +1.50 in the first patient and + 2.50 DS in the second patient; in the LE were: +1.50 and + 2.00 DS, respectively. The participants' ages and visual functions data are summarized in Table 9.1.

<table>
<thead>
<tr>
<th></th>
<th>SIPs (RE)</th>
<th>TVPs (Binocular)</th>
<th>Hemianopic (Binocular)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>24.50 ± 6.50 (18 to 51)</td>
<td>42.50 ± 11.00 (28 to 67)</td>
<td>67 and 70</td>
</tr>
<tr>
<td>VA (logMAR)</td>
<td>-0.10 ± 0.11 (-0.30 to 0.10)</td>
<td>0.20 ± 0.20 (-0.14 to 0.40)</td>
<td>0.00 and -0.10</td>
</tr>
<tr>
<td>Log CS</td>
<td>1.70 ± 0.08 (1.60 to 1.95)</td>
<td>1.50 ± 0.30 (0.60 to 1.85)</td>
<td>1.65</td>
</tr>
</tbody>
</table>

The simulated FoV of the 50 participants for the four FoV sizes (from 20° to 5°) were: 20° ± 1° (Means ± SD), range 18° to 22°; 15° ± 0.75°, range 13.50° to 16.50°; 10.50° ± 0.75°, range 9.50° to 12°; 5° ± 0.50°, range 4° to 6°; respectively. The FoV of the TVP groups ranged from 4° to 21°. In detail, seven participants had FoV of 18° to 21°, eight had FoV of 10° to 12° and five had FoV of 4° to 6°. In the hemianopic patients, the first patient had right hemianopia and the second patient had left hemianopia (the Esterman VF plots for both participants are shown in Appendix Three).
9.4 The TVPs Reported Outcome

The TVPs’ reported outcome was assessed by exploring their feelings towards mobility situations using the IMQ (Turano et al., 1999a) and the LVQOL questionnaire (Wolffsohn and Cochrane, 2000), which contains sub-domains dealing with distance vision, mobility and lighting; adjustment; reading and fine work; and ADL (Appendix One). The TVPs’ median scores for each of these are summarized in Table 9.2.

Table 9.2 The TVPs QoL score in the IMQ, LVQOL questionnaire and in the LVQOL sub-domains

<table>
<thead>
<tr>
<th></th>
<th>Median (range)</th>
<th>Median (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMQ overall</td>
<td>3 (2 to 5)</td>
<td></td>
</tr>
<tr>
<td>LVQOL overall</td>
<td>3 (5 to 2)</td>
<td></td>
</tr>
<tr>
<td>LVQOL sub-domains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>distance vision, mobility and lighting</td>
<td>3 (4 to 1)</td>
<td>3 (4 to 2)</td>
</tr>
<tr>
<td>reading and fine work</td>
<td>5 (5 to 1)</td>
<td>5 (5 to 3)</td>
</tr>
</tbody>
</table>

IMQ scores range from 1 to 5: 1 represents no difficulty and 5 represents extreme difficulty. LVQOL scores range from 5 to 1: 5 refers to no problems and 1 refers to great problems.
9.5 The AVA Test Result

Approximately 94% and 99% of the data collected from the SIPs and TVPs respectively were included in the analysis. The missing data were due to:

i. one of the simulators for the SIPs, which did not produce the targeted FoV;
ii. the accuracy of the direction or detecting the central cross was incorrect; or
iii. the target was missed.

These data were taken out of the analysis (as described earlier in Chapter 8, section 8.4). The AVA data, in these two groups, were investigated for normality: the Kolmogorov-Smirnov test showed that some of the DT scores were normally distributed ($p > 0.05$) and that some data were not normally distributed ($p < 0.05$), therefore, non-parametric tests were used throughout. All of the data collected from the hemianopic patients were included in the analysis. The hemianopic DT scores collected from the AVA test, were investigated for normality, Kolmogorov-Smirnov showed that the DT scores were normally distributed ($p > 0.05$), therefore, parametric tests were used.

9.5.1 The Direction and Location Accuracy in the SIPs, TVPs and Hemianopics

In the SIPs, the accuracy of correctly identifying the target location and direction did not vary with eccentricity on either visit in any of the four FoV sizes (Table 9.3). The Chi-square test for independence showed that on both visits no significant association was found between the target eccentricity with the accuracy of detecting the target location and target direction (Table 9.4). If detecting the target locations was better on the second visit, this may suggest a learning effect. The data collected from the four annuli in each visit were pooled and no significant association was found between the visit as a factor and detecting the target locations and direction, in SIPs 20° $\chi^2 (1, n=3116) = 0.67, p = 0.41; \chi^2 (1, n=3116) = 0.00, p = 1.00$, respectively; in SIPs 15° $\chi^2 (1, n=3170) = 0.00, p = 1.00; \chi^2 (1, n=3170) = 1.00, p =$
0.32, respectively; in SIPs \(10^\circ\) \(\chi^2\) (1, \(n=2864\)) = 0.20, \(p = 0.65\); \(\chi^2\) (1, \(n=2864\)) = 1.00, \(p = 0.32\), respectively and, finally, in SIPs \(5^\circ\) \(\chi^2\) (1, \(n=3141\)) = 0.00, \(p = 1.00\); \(\chi^2\) (1, \(n=3141\)) = 1.00, \(p = 0.32\), respectively.
Table 9.3 The accuracy of reporting the target position and direction in the SIPs

<table>
<thead>
<tr>
<th></th>
<th>SIPS 20°</th>
<th>SIPS 15°</th>
<th>SIPS 10°</th>
<th>SIPS 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Position Accuracy</strong></td>
<td>First / Second visit</td>
<td>First / Second visit</td>
<td>First / Second visit</td>
<td>First / Second visit</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; annulus</td>
<td>99.50% / 100%</td>
<td>100% / 99.50%</td>
<td>100% / 100%</td>
<td>100% / 100%</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; annulus</td>
<td>99.00% / 99.50%</td>
<td>99% / 99.50%</td>
<td>99.50 / 100%</td>
<td>100% / 100%</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; annulus</td>
<td>98.50% / 99.00%</td>
<td>99% / 99%</td>
<td>99% / 99%</td>
<td>99.50% / 99.50%</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; annulus</td>
<td>99.50% / 99.00%</td>
<td>99% / 99%</td>
<td>98% / 99%</td>
<td>100% / 100%</td>
</tr>
<tr>
<td><strong>Direction Accuracy</strong></td>
<td>First / Second visit</td>
<td>First / Second visit</td>
<td>First / Second visit</td>
<td>First / Second visit</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; annulus</td>
<td>100% / 100%</td>
<td>100% / 99.50%</td>
<td>100% / 100%</td>
<td>100% / 100%</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; annulus</td>
<td>100% / 95.50%</td>
<td>100% / 100%</td>
<td>100% / 100%</td>
<td>100% / 100%</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; annulus</td>
<td>99.50% / 99.00%</td>
<td>100% / 100%</td>
<td>100% / 100%</td>
<td>99.50% / 100%</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; annulus</td>
<td>100% / 100%</td>
<td>100% / 100%</td>
<td>99% / 100%</td>
<td>100% / 100%</td>
</tr>
</tbody>
</table>
Table 9.4 The Chi-square test investigating the impact of target location on reporting the target location and direction in the SIPs

<table>
<thead>
<tr>
<th>First visit</th>
<th>Position Accuracy</th>
<th>Direction accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs 20°</td>
<td>$\chi^2$ (3, n=1558) = 3.16, $p = 0.37$</td>
<td>$\chi^2$ (3, n=1558) = 3.00, $p = 0.37$</td>
</tr>
<tr>
<td>SIPs 15°</td>
<td>$\chi^2$ (3, n=1585) = 4.68, $p = 0.20$</td>
<td>$\chi^2$ (3, n=1585) = 6.10, $p = 0.11$</td>
</tr>
<tr>
<td>SIPs 10°</td>
<td>$\chi^2$ (3, n=1432) = 5.40, $p = 0.10$</td>
<td>$\chi^2$ (3, n=1432) = 3.05, $p = 0.38$</td>
</tr>
<tr>
<td>SIPs 5°</td>
<td>$\chi^2$ (3, n=1571) = 3.01, $p = 0.39$</td>
<td>$\chi^2$ (3, n=1571) = 3.00, $p = 0.39$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Second visit</th>
<th>Position Accuracy</th>
<th>Direction accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs 20°</td>
<td>$\chi^2$ (3, n=1558) = 5.25, $p = 0.15$</td>
<td>$\chi^2$ (3, n=1558) = 2.98, $p = 0.40$</td>
</tr>
<tr>
<td>SIPs 15°</td>
<td>$\chi^2$ (3, n=1585) = 3.34, $p = 0.34$</td>
<td>$\chi^2$ (3, n=1585) = 3.04, $p = 0.39$</td>
</tr>
<tr>
<td>SIPs 10°</td>
<td>$\chi^2$ (3, n=1432) = 5.20, $p = 0.10$</td>
<td>$\chi^2$ (3, n=1432) = 5.99, $p = 0.11$</td>
</tr>
<tr>
<td>SIPs 5°</td>
<td>$\chi^2$ (3, n=1571) = 3.00, $p = 0.39$</td>
<td>$\chi^2$ (3, n=1570) = 6.02, $p = 0.11$</td>
</tr>
</tbody>
</table>

* indicates statistical significance, $p < 0.05
In the three TVP groups, the accuracy of correctly reporting the target location and direction did not differ with eccentricity (Table 9.5). The Chi-square test gave no statistical evidence to suggest that there is association between the target eccentricity and the accuracy of detecting the target location and target direction (Table 9.6).

Table 9.5 The mean accuracy of reporting the target location and direction in the TVPs

<table>
<thead>
<tr>
<th>Position Accuracy</th>
<th>TVPs 20°</th>
<th>TVPs 10°</th>
<th>TVPs 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st annulus</td>
<td>97.50%</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>100%</td>
<td>100%</td>
<td>98%</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>4th annulus</td>
<td>100%</td>
<td>99%</td>
<td>99%</td>
</tr>
</tbody>
</table>

Table 9.6 The Chi-square test exploring the influence of target location on reporting the target location and direction in the TVPs

<table>
<thead>
<tr>
<th>First visit</th>
<th>Position Accuracy</th>
<th>Direction accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVPs 20°</td>
<td>$\chi^2 (3, n=202) = 3.95, p = 0.27$</td>
<td>$\chi^2 (3, n=202) = 3.95, p = 0.27$</td>
</tr>
<tr>
<td>TVPs 10°</td>
<td>$\chi^2 (3, n=230) = 2.12, p = 0.55$</td>
<td>$\chi^2 (3, n=230) = 2.98, p = 0.40$</td>
</tr>
<tr>
<td>TVPs 5°</td>
<td>$\chi^2 (3, n=151) = 1.96, p = 0.58$</td>
<td>$\chi^2 (3, n=151) = 3.58, p = 0.31$</td>
</tr>
</tbody>
</table>

* indicates statistical significance, $p < 0.05$
In the two hemianopes, correctly identifying the target location and direction did not change with eccentricity (Table 9.7). The Chi-square test suggested that there was no significant association between the target eccentricity and the accuracy of detecting the target location and target direction. Further, the Chi-square test indicated that percentage correct identification of the target location and direction did not differ between the functioning and non-functioning side of the VF (Table 9.7).

Table 9.7 The mean accuracy of identifying target location and direction, Chi-square test investigating impact of target location and side of VF (functioning and non-functioning) on reporting target location and direction for hemianopic patients

<table>
<thead>
<tr>
<th>Position Accuracy</th>
<th>Target location</th>
<th>Field side</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st annulus</td>
<td>95.00%</td>
<td></td>
</tr>
<tr>
<td>2nd annulus</td>
<td>91.00%</td>
<td></td>
</tr>
<tr>
<td>3rd annulus</td>
<td>90.00%</td>
<td>$\chi^2 (3, n=63) = 3.58, p = 0.31$</td>
</tr>
<tr>
<td>4th annulus</td>
<td>93.00%</td>
<td></td>
</tr>
</tbody>
</table>

Direction accuracy

<table>
<thead>
<tr>
<th>Position Accuracy</th>
<th>Target location</th>
<th>Field side</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st annulus</td>
<td>94.00%</td>
<td></td>
</tr>
<tr>
<td>2nd annulus</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>3rd annulus</td>
<td>100%</td>
<td>$\chi^2 (3, n=63) = 2.98, p = 0.39$</td>
</tr>
<tr>
<td>4th annulus</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

* indicates statistical significance, $p < 0.05$
9.5.2 Performance of the SIPs

The DT was different for the different annuli, with the DT being longer as the stimulus became more peripheral (Table 9.8). For example, in SIPs 15° (in first visit) an increase by a factor of three was found for DT at the 3rd annulus compared to the 2nd annulus (Table 9.8). Further, when looking at the box-plot it can be seen that the DT increased as eccentricity increased in SIPs 10° (Figure 9.1). In general, as the FoV contracted, the DT became noticeably longer within the same annulus. For instance, the DT (in second visit) at the 3rd annulus in SIPs 20° was four times greater than for SIPs 5° (Table 9.8).

Table 9.8 The median ± IQR of the SIPs DT (in seconds) with different simulators on each visit and the Wilcoxon test comparing the DT scores between the two visits

<table>
<thead>
<tr>
<th></th>
<th>1st annulus</th>
<th>2nd annulus</th>
<th>3rd annulus</th>
<th>4th annulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs 20° visit 1</td>
<td>1.37 ± 0.80</td>
<td>1.20 ± 0.67</td>
<td>3.71 ± 1.91</td>
<td>4.63 ± 1.98</td>
</tr>
<tr>
<td>SIPs 20° visit 2</td>
<td>1.10 ± 0.46</td>
<td>1.13 ± 0.66</td>
<td>3.44 ± 1.94</td>
<td>4.49 ± 1.94</td>
</tr>
<tr>
<td>Wilcoxon test</td>
<td>Z=-4.37, p &lt;0.0001*</td>
<td>Z=-1.91, p =0.06</td>
<td>Z=-0.03, p =0.98</td>
<td>Z=-1.54, p =0.12</td>
</tr>
<tr>
<td>SIPs 15° visit 1</td>
<td>1.53 ± 0.64</td>
<td>1.62 ± 0.77</td>
<td>4.98 ± 1.91</td>
<td>5.82 ± 2.22</td>
</tr>
<tr>
<td>SIPs 15° visit 2</td>
<td>1.19 ± 0.61</td>
<td>1.56 ± 1.09</td>
<td>4.10 ± 2.99</td>
<td>5.40 ±2.25</td>
</tr>
<tr>
<td>Wilcoxon test</td>
<td>Z=-3.68, p &lt;0.0001*</td>
<td>Z=-0.73, p =0.47</td>
<td>Z=-0.32, p =0.75</td>
<td>Z=-0.36, p =0.72</td>
</tr>
<tr>
<td>SIPs 10° visit 1</td>
<td>1.59 ± 0.57</td>
<td>2.29 ± 1.22</td>
<td>5.04 ± 1.94</td>
<td>6.69 ± 3.08</td>
</tr>
<tr>
<td>SIPs 10° visit 2</td>
<td>1.35 ± 0.80</td>
<td>1.80 ± 1.57</td>
<td>4.53 ± 2.20</td>
<td>5.79 ± 2.33</td>
</tr>
<tr>
<td>Wilcoxon test</td>
<td>Z=-2.68, p = 0.01*</td>
<td>Z=-1.11, p =0.27</td>
<td>Z=-0.48, p =0.63</td>
<td>Z=-1.87, p =0.06</td>
</tr>
<tr>
<td>SIPs 5° visit 1</td>
<td>3.18 ± 3.20</td>
<td>6.37 ± 5.63</td>
<td>13.15 ± 9.21</td>
<td>12.45 ± 6.02</td>
</tr>
<tr>
<td>SIPs 5° visit 2</td>
<td>2.38 ± 1.96</td>
<td>10.50 ± 6.92</td>
<td>12.68 ± 9.43</td>
<td>11.31 ± 4.80</td>
</tr>
<tr>
<td>Wilcoxon test</td>
<td>Z=-3.86, p &lt;0.0001*</td>
<td>Z=-1.31, p =0.19</td>
<td>Z=-0.42, p =0.68</td>
<td>Z=-1.58, p =0.12</td>
</tr>
</tbody>
</table>

* indicates statistical significance, p < 0.05
The sensitivity of the AVA test was investigated by exploring the effect of FoV and target location on the DT scores, using the Friedman test and Spearman rank order correlation test. One of the Spearman test assumptions is of independent data. However, this is not the case in this study, as the same 50 participants did the same test for four times with four simulators. In order to make the data independent and avoid any within-subject effect on the relationship positively or negatively, a bootstrap resampling statistical technique was used (Wilcox, 2011, Efron and Tibshirani, 1993). The idea behind the bootstrap statistic is to divide the sample into four groups in accordance to the FoV size (in each group there are 12 participants) then randomly assign participants to each group. Participants placed in one group will not appear in any one of the other three groups. Then the relationship between FoV and DT scores was tested. This test was conducted 1000 times using the R project for statistical computing (http://www.r-project.org/) in order to give all participants a chance to be included in the test, have a robust result and avoid any impact of the within-subject effect. The reported correlation coefficient value and the significance value is the median of the 1000 values.

Figure 9.1 Box-plot of DT scores at the different annuli for SIPs 10° (first visit), showing that DT scores were responsive to change in target location
To begin with, the Friedman test had shown that the FoV was statistically significantly ($p < 0.0001$) influencing the DT scores throughout the different annuli and on both visits (Table 9.9). The relationship between the FoV and DT scores was explored at each eccentricity separately on each visit using the Spearman test. When the bootstrap resampling technique was used, the Spearman test showed a highly significant negative relationship between the FoV and DT at each annulus and on each visit with shorter DT associated with bigger FoV.

On the first visit the correlation coefficient ($r$) values, from 1st to 4th annulus, were: $r = -0.55$, $p = 0.005$; $r = -0.77$, $p < 0.0001$; $r = -0.76$, $p < 0.0001$ and $r = -0.74$, $p < 0.0001$; respectively. On the second visit the $r$ values were: $r = -0.56$, $p < 0.0001$; $r = -0.75$, $p < 0.0001$; $r = -0.70$, $p < 0.0001$ and $r = -0.70$, $p < 0.0001$, respectively. Interestingly, the relationship between the FoV and DT at the 1st annulus was consistently not as strong as the relationship with the other annuli.

Table 9.9 The impact of FoV on DT scores as tested using Friedman test

<table>
<thead>
<tr>
<th></th>
<th>First visit</th>
<th>Second visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st annulus</td>
<td>$\chi^2(3,45)=67.27, p&lt;0.0001^*$</td>
<td>$\chi^2(3,45)=69.33, p&lt;0.0001^*$</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>$\chi^2(3,45)=98.4, p&lt;0.0001^*$</td>
<td>$\chi^2(3,45)=95.33, p&lt;0.0001^*$</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>$\chi^2(3,45)=97.87, p&lt;0.0001^*$</td>
<td>$\chi^2(3,45)=98.30, p&lt;0.0001^*$</td>
</tr>
<tr>
<td>4th annulus</td>
<td>$\chi^2(3,45)=93.55, p&lt;0.0001^*$</td>
<td>$\chi^2(3,45)=83.85, p&lt;0.0001^*$</td>
</tr>
</tbody>
</table>

* indicates statistical significance, $p < 0.05$

The Friedman test showed that the DT scores were statistically significantly ($p < 0.0001$) depending on the target location across the four FoV sizes (SIPs 20° to SIPs 5°) and on each visit (Tables 9.8 and 9.10). Using the bootstrap resampling method, the Spearman test showed that there was a statistically significant positive relationship between the target location and DT, with longer DT responses as the target becomes more peripheral. The correlation coefficient ($r$) values in SIPs 20° were (for the two visits) $r = 0.75$, $p < 0.0001$; $r = 0.80$, $p < 0.0001$, respectively; in SIPs 15° $r = 0.82$, $p < 0.0001$; $r = 0.82$, $p < 0.0001$, respectively.
respectively; in SIPs 10° $r = 0.84$, $p < 0.0001$; $r = 0.80$, $p < 0.0001$, respectively and SIPs 5° $r = 0.53$, $p = 0.02$; $r = 0.58$, $p < 0.0001$, respectively (Figure 9.2).

Table 9.10 Friedman test exploring the impact of target eccentricity on DT scores

<table>
<thead>
<tr>
<th></th>
<th>First visit</th>
<th>Second visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs 20°</td>
<td>$\chi^2 (3,45) = 108, p &lt; 0.0001^*$</td>
<td>$\chi^2 (3,45) = 119, p &lt; 0.0001^*$</td>
</tr>
<tr>
<td>SIPs 15°</td>
<td>$\chi^2 (3,45) = 119.7, p &lt; 0.0001^*$</td>
<td>$\chi^2 (3,45) = 119, p &lt; 0.0001^*$</td>
</tr>
<tr>
<td>SIPs 10°</td>
<td>$\chi^2 (3,45) = 112, p &lt; 0.0001^*$</td>
<td>$\chi^2 (3,45) = 100.6, p &lt; 0.0001^*$</td>
</tr>
<tr>
<td>SIPs 5°</td>
<td>$\chi^2 (3,45) = 73.29, p &lt; 0.0001^*$</td>
<td>$\chi^2 (3,45) = 82.5, p &lt; 0.0001^*$</td>
</tr>
</tbody>
</table>

* indicates statistical significance, $p < 0.05$

Figure 9.2 Friedman test exploring the impact of target eccentricity on DT scores. A highly significant positive relationship was found between both variables with longer DT scores being associated with more peripheral targets.
The repeatability of the AVA test was investigated using the Wilcoxon signed-rank test and Bland-Altman test. Firstly, the Wilcoxon test was conducted to compare the DT scores at each annulus (1st to 4th annulus) within the same FoV size (Table 9.8). The Wilcoxon test showed no significant difference in DT scores between the two visits except the scores at the 1st annulus (Table 9.8).

A Bland-Altman test was conducted to investigate if there was a clear pattern to indicate that the majority of the SIPs, within the same FoV size, were better (or worse) performers on either visit. The means of the differences and the LoA for each FoV size are listed in Table 9.11. It can be seen that the differences in scores did not increase as the mean of the DT increased (Figures 9.3, 9.4, 9.5, and 9.6). The means of difference between both visits were minimal (<1s) except in SIPs 5°, yet the variation in this group was high (Table 9.8). The mean difference indicated that the participants were slower on the first visit, although individual data points are scattered above and below the zero difference which suggest that the participants were sometimes slower on the first visit and sometimes slower on the second in each FoV size. This result suggests that there is little learning effect on the participants' performances while doing the AVA test over a short period of time (i.e. one to two weeks). However, this variation in scores may not improve the participant's functional performance in everyday activities.
Table 9.11 Limits of agreements for each eccentricity in each FoV size

<table>
<thead>
<tr>
<th>First visit vs. Second visit</th>
<th>1(^{st}) annulus</th>
<th>2(^{nd}) annulus</th>
<th>3(^{rd}) annulus</th>
<th>4(^{th}) annulus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LoA in seconds</td>
<td>LoA in seconds</td>
<td>LoA in seconds</td>
<td>LoA in seconds</td>
</tr>
<tr>
<td></td>
<td>(Mean of difference)</td>
<td>(Mean of difference)</td>
<td>(Mean of difference)</td>
<td>(Mean of difference)</td>
</tr>
<tr>
<td>SIPs 20°</td>
<td>-0.83 to 1.75 (0.46)</td>
<td>-0.96 to 1.44 (0.24)</td>
<td>-2.86 to 3.52 (0.33)</td>
<td>-3.1 to 3.6 (0.27)</td>
</tr>
<tr>
<td>SIPs 15°</td>
<td>-0.55 to 1.13 (0.29)</td>
<td>-1.63 to 1.43 (-0.10)</td>
<td>-3.00 to 2.72 (-0.14)</td>
<td>-3.13 to 3.23 (0.05)</td>
</tr>
<tr>
<td>SIPs 10°</td>
<td>-1.23 to 1.51 (0.14)</td>
<td>-1.94 to 2.76 (0.41)</td>
<td>-4.1 to 4.95 (0.44)</td>
<td>-3.00 to 5.42 (1.21)</td>
</tr>
<tr>
<td>SIPs 5°</td>
<td>-4.81 to 7.39 (1.29)</td>
<td>-10.67 to 8.13 (-1.27)</td>
<td>-14.5 to 14.9 (0.2)</td>
<td>-11.62 to 13.86 (1.12)</td>
</tr>
</tbody>
</table>
Figure 9.3 Bland-Altman plot of the DT scores in SIPS 20°. The dashed line is the mean difference of the pooled data. The mean difference of the four annuli are: 0.46, 0.24, 0.33 and 0.27, respectively. The LoA of the four annuli are: -0.83 to 1.75 seconds, -0.96 to 1.44 seconds, -2.86 to 3.52 seconds and -3.10 to 3.60 seconds.

Figure 9.4 The difference in DT scores between both visits in SIPS 15° shown as Bland-Altman plot. The dashed line is the mean difference of the pooled data. The mean difference of the four annuli are: 0.29, -0.10, -0.14 and 0.05, respectively. The LoA of the four annuli are: -0.55 to 1.13 seconds, -1.63 to 1.43 seconds, -3.00 to 2.72 seconds and -3.13 to 3.23 seconds.
Figure 9.5 Bland-Altman plot of DT scores in SIPs 10° showing the difference between both visits. The dashed line is the mean difference of the pooled data. The mean difference of the four annuli are: 0.14, 0.41, 0.44 and 1.21. The LoA of the four annuli are: 1.51 to -1.23 seconds, 2.76 to -1.94 seconds, 4.95 to -4.10 seconds and 5.42 to -3.00 seconds.

Figure 9.6 Bland-Altman plot of the DT scores in SIPs 5°. The dashed line is the mean difference of the pooled data. The mean difference of the four annuli are: 1.29, -1.27, 0.20 and 1.12, respectively. The LoA of the four annuli are: 7.39 to -4.81 seconds, 8.13 to -10.67 seconds, 14.9 to -14.50 seconds and 13.86 to -11.62 seconds.
9.5.3 Performance of the TVPs

The DT scores at the 1\textsuperscript{st} annulus were greater than the 2\textsuperscript{nd} annulus in two TVPs groups (Table 9.12). However, the DT scores then became progressively longer as the target moved from the 2\textsuperscript{nd} annulus towards the more peripheral locations. For instance, in TVPs 10° a factor of at least 4x was found between DT at the 2\textsuperscript{nd} annulus and DT at the 4\textsuperscript{th} annulus (Table 9.12). The FoV also influenced the DT, for example, the DT scores at the 3\textsuperscript{rd} annulus gradually increased as the FoV became smaller. Further, the effect of the target location on the DT scores was obvious when a descriptive box-plot was considered in TVP 10° (Figure 9.7).

Table 9.12 The median ± IQR of the TVPs DT (in seconds) scores and the Friedman test investigating the effect of the FoV on the DT scores

<table>
<thead>
<tr>
<th>TVPs 20°</th>
<th>1\textsuperscript{st} annulus</th>
<th>2\textsuperscript{nd} annulus</th>
<th>3\textsuperscript{rd} annulus</th>
<th>4\textsuperscript{th} annulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVPs 10°</td>
<td>2.16 ± 4.49</td>
<td>1.53 ± 1.42</td>
<td>3.31 ± 3.47</td>
<td>5.30 ± 3.84</td>
</tr>
<tr>
<td>TVPs 5°</td>
<td>2.52 ± 4.02</td>
<td>2.80 ± 1.61</td>
<td>5.25 ± 2.96</td>
<td>6.27 ± 4.17</td>
</tr>
<tr>
<td>Friedman FoV</td>
<td>$\chi^2 = 0.80, p=0.82$</td>
<td>$\chi^2 = 8.40, p = 0.02^*$</td>
<td>$\chi^2 = 8.40 , p = 0.02^*$</td>
<td>$\chi^2 = 10, p = 0.007^*$</td>
</tr>
</tbody>
</table>

* indicates statistical significance, $p < 0.05$

Figure 9.7 A box-plot of the DT scores at the different annuli in TVPs 10°. The graph shows that the DT scores were changing in accordance to the change in target location.
The AVA test sensitivity in the TVPs was investigated by looking at the effect of the FoV and the target location on the DT scores. The Friedman test showed that the FoV did not impact the DT scores at the 1st annulus, however, a statistically significant \( (p < 0.05) \) impact of the FoV on the DT scores in the remaining annuli was found (Table 9.12). The relationship between the FoV and DT scores was investigated at each eccentricity separately using the Spearman rank order correlation. The Spearman test showed a highly significant negative relationship between the FoV and DT scores for the 2nd, 3rd and 4th annulus. The test suggested that faster DT scores are associated with bigger FoV. The correlation coefficient \( (r) \) values, from 2nd to 4th annulus, were: \( r = -0.60, p = 0.003; r = -0.40, p = 0.04; r = -0.54, p = 0.007 \), respectively. However, no significant relationship was found between the FoV and 1st annulus, \( r = -0.20, p = 0.28 \).

The Friedman test showed a statistically significant \( (p < 0.05) \) effect of the target location on the DT scores within TVPs 20° and TVPs 10°, but no significant effect was found in TVPs 5° (Table 9.13). The Spearman test showed that there was a statistically significant positive relationship between the target location and DT, the correlation coefficient in TVPs 20° \( r = 0.50, p = 0.005 \); in TVPs 10° \( r = 0.60, p < 0.0001 \) and TVPs 5° \( r = 0.50, p = 0.02 \).

Table 9.13 Friedman test exploring the impact of target eccentricity on DT scores

<table>
<thead>
<tr>
<th>Target location</th>
<th>( \chi^2 \text{(3,5)} = )</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVPs 20°</td>
<td>9.72</td>
<td>0.02*</td>
</tr>
<tr>
<td>TVPs 10°</td>
<td>10.65</td>
<td>0.014*</td>
</tr>
<tr>
<td>TVPs 5°</td>
<td>4.20</td>
<td>0.24</td>
</tr>
</tbody>
</table>

* indicates statistical significance, \( p < 0.05 \)
The Spearman rank order correlation test was conducted to investigate the relationship between the TVPs’ VA, CS, the IMQ and LVQOL questionnaire scores on one hand and the DT scores on the other hand. It was found that there was a moderate but not significant relationship between the participant's VA and log CS and the DT at the 1st annulus ($r= 0.4, p = 0.07$; $r =0.40, p = 0.06$, respectively), however, no relationship was found with the DT at the rest of the annuli ($r \leq 0.10, p > 0.05$). A moderate but not statistically significant relationship was found between the median scores of the overall IMQ and the DT scores at the 3rd and 4th annulus ($r = 0.30, p = 0.12$; $r = 0.34, p = 0.07$, respectively), but no relationship was found at the 1st and 2nd annulus ($r= 0.20, p = 0.23$; $r = 0.05, p = 0.43$, respectively). After investigating the relationship between the DT scores and the LVQOL questionnaire several times (i.e. overall scores and with LVQOL sub-domains), the Bonferroni correction was applied and the $p$ value was set at 0.01. In detail, no significant relationship was found between the DT scores at the different annuli and the median scores of the overall LVQOL ($r \leq 0.1, p > 0.01$). However, when the relationship between the DT scores and the median scores of the four sub-domains within the LVQOL questionnaire was considered (distance vision, mobility and lighting; adjustment; reading and fine work and activity of daily living), a moderate but not significant relationship was found between the DT scores at the 3rd and 4th annulus with the first domain (i.e. distance vision, mobility and lighting) ($r = -0.40, p > 0.01$), yet no relationship was found either at the 1st and 2nd annulus or with the latter three sub-domains. This result may suggest that the participants who responded with fewer problems in the first domain scored shorter DT at the 3rd and 4th annulus.
9.5.4 Comparison of SIPs and TVPs Performance on the AVA Test

Comparing the TVP and SIP performances in the AVA test showed that the TVPs were slower than the SIPs at the 1st annulus regardless of the FoV size (Table 9.14). Other than this difference, no systematic differences were found between the two matched groups (Table 9.14).

Table 9.14 The Md. ± IQR of the SIPs and TVPs scores on the AVA test

<table>
<thead>
<tr>
<th></th>
<th>1st annulus</th>
<th>2nd annulus</th>
<th>3rd annulus</th>
<th>4th annulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVPs 20°</td>
<td>2.16 ± 4.49</td>
<td>1.53 ± 1.42</td>
<td>3.31 ± 3.47</td>
<td>5.30 ± 3.84</td>
</tr>
<tr>
<td>SIPs 20°</td>
<td>1.37 ± 0.80</td>
<td>1.20 ± 0.67</td>
<td>3.71 ± 1.91</td>
<td>4.63 ± 1.98</td>
</tr>
<tr>
<td>TVPs 10°</td>
<td>5.57 ± 7.97</td>
<td>2.23 ± 2.02</td>
<td>5.55 ± 1.36</td>
<td>9.04 ± 4.71</td>
</tr>
<tr>
<td>SIPs 10°</td>
<td>1.59 ± 0.57</td>
<td>2.29 ± 1.22</td>
<td>5.04 ± 1.94</td>
<td>6.69 ± 3.08</td>
</tr>
<tr>
<td>TVPs 5°</td>
<td>5.11 ± 25.72</td>
<td>5.07 ± 13.37</td>
<td>11.31 ± 19.80</td>
<td>19.99 ± 31.75</td>
</tr>
<tr>
<td>SIPs 5°</td>
<td>3.18 ± 3.20</td>
<td>6.37 ± 5.63</td>
<td>13.15 ± 9.21</td>
<td>12.45 ± 6.02</td>
</tr>
</tbody>
</table>

Using the Mann-Whitney U test, a statistically significant difference was found in DT at the 1st annulus between the TVPs and the SIPs for FoV of 20° and 10° (Table 9.15). However, no statistically significant difference was found with the FoV of 5°. In the other three annuli there was no statistical significant difference between the TVPs and SIPs in DT scores (Table 9.15).

Table 9.15 Mann-Whitney U test comparing the TVP and SIP DT scores

<table>
<thead>
<tr>
<th></th>
<th>FoV 20°</th>
<th>FoV 10°</th>
<th>FoV 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st annulus</td>
<td>U = 39.00, Z = -2.44, p = 0.01*</td>
<td>U = 93, Z = -2.1, p = 0.04*</td>
<td>U = 106, Z = -0.49, p = 0.64</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>U = 101, Z = -1.75, p = 0.08</td>
<td>U = 123, Z = -1.27, p = 0.21</td>
<td>U = 95, Z = -0.82, p = 0.43</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>U = 116, Z = -1.31, p = 0.20</td>
<td>U = 148, Z = -0.80, p = 0.44</td>
<td>U = 122, Z = -0.1, p = 0.94</td>
</tr>
<tr>
<td>4th annulus</td>
<td>U = 103, Z = -1.64, p = 0.10</td>
<td>U = 165, Z = -0.37, p = 0.72</td>
<td>U = 75, Z = -1.42, p = 0.17</td>
</tr>
</tbody>
</table>

* indicates statistical significance, p < 0.05
9.5.5 Performance of the Hemianopic Patients

The DT scores of the AVA test were recorded and divided into two categories: the locations falling in the non-functioning side (e.g. 1.30, 3 and 4.30 o'clock meridians) and the locations falling in the functioning side (e.g., 7.30, 9 and 10.30 o'clock meridians). The DT for targets that were presented at the 12 and 6 o'clock meridians were omitted from the analysis as these two locations fell on the border between the functioning and non-functioning sides of the VF.

The DT scores for the non-functioning side were always greater than the DT in the functioning area. It was also noticeable that the variation (i.e. the SD) of the DT scores at each annulus was almost the double the variation recorded in the functioning area (Table 9.16). One-way analysis of covariance (ANCOVA) was conducted to investigate the effect of the field side on the DT scores while target location was the covariant. No statistically significant effect of the field side on the DT scores was found ($p > 0.05$), but this may be due to the high variation in the 1st annulus scores which may mask the field effect. When the DT scores at the 1st annulus were excluded from the analysis, the one-way ANCOVA test showed a statistically significant effect of the field side on the DT scores, $F(1, 44) = 7.35, p = 0.010$; partial eta squared = 0.30. The partial eta squared value indicates that about 30% of the variance in the DT scores could be explained by field side that the target fell within.

Table 9.16 Means ± SD of the DT scores in the functioning and non-functioning side of the VF

<table>
<thead>
<tr>
<th></th>
<th>Functioning side</th>
<th>Non-functioning side</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st annulus</td>
<td>3.50 ± 2.48</td>
<td>6.85 ± 9.82</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>1.38 ± 0.413</td>
<td>2.16 ± 1.52</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>1.744 ± 0.375</td>
<td>2.389 ± 0.864</td>
</tr>
<tr>
<td>4th annulus</td>
<td>3.10 ± 1.26</td>
<td>4.05 ± 1.83</td>
</tr>
</tbody>
</table>
9.6 The Relationship between the Mobility Scores and AVA Test

The direct relationship between the AVA test and the mobility scores was investigated using the Spearman test in both the SIPs and TVPs. In the SIPs the resampling bootstrap was used to avoid any within-subject effect. In the SIPs, a highly significant relationship was found between the DT scores at the four annuli, and both mobility measures (Table 9.17). In the TVPs, there was only a small to moderate relationship between the DT scores in the three more peripheral annuli (from 2nd to 4th annulus) and the mobility scores, yet this relationship was not statistically significant: for PPWS, r ranged from -0.20 to -0.30, p > 0.05 and for collisions, r ranged from 0.20 to 0.30, p > 0.05. There was no relationship between the DT scores for the 1st annulus and the mobility measures.

Table 9.17 The results of Spearman’s test to investigate the relationship between the DT scores and the mobility scores for the SIPs

<table>
<thead>
<tr>
<th>Target Location</th>
<th>PPWS First visit</th>
<th>PPWS Second visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st annulus</td>
<td>r = -0.32, p &lt; 0.0001</td>
<td>r = -0.37, p &lt; 0.0001</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>r = -0.46, p &lt; 0.0001</td>
<td>r = -0.52, p &lt; 0.0001</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>r = -0.53, p &lt; 0.0001</td>
<td>r = -0.50, p &lt; 0.0001</td>
</tr>
<tr>
<td>4th annulus</td>
<td>r = -0.60, p &lt; 0.0001</td>
<td>r = -0.56, p &lt; 0.0001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Target Location</th>
<th>Collisions First visit</th>
<th>Collisions Second visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st annulus</td>
<td>r = 0.44, p &lt; 0.0001</td>
<td>r = 0.40, p &lt; 0.0001</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>r = 0.51, p &lt; 0.0001</td>
<td>r = 0.50, p &lt; 0.0001</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>r = 0.50, p &lt; 0.0001</td>
<td>r = 0.44, p &lt; 0.0001</td>
</tr>
<tr>
<td>4th annulus</td>
<td>r = 0.50, p &lt; 0.0001</td>
<td>r = 0.40, p &lt; 0.0001</td>
</tr>
</tbody>
</table>

* indicates statistical significance, p < 0.05

The Spearman relationship between the DT and the mobility scores does not take into account the effect of the FoV on the relationship. The FoV is expected to control the participants’ performance on both tests. To investigate the relationship between the two measures while controlling the effect of the FoV, a partial relationship test was conducted;
the resampling bootstrap was used in the SIPs. In the SIPs, a statistically significant relationship was found between the DT scores at the 3rd and 4th annulus with the PPWS on both visits (Table 9.18). Further, a statistically significant relationship was found between collision scores and the DT at the 2nd, 3rd and 4th annulus on both visits (Table 9.18). In the TVPs, the partial relationship showed that the relationship was not markedly impacted at the 2nd, 3rd and 4th annulus as the relationship strength remained within the same range, with the PPWS r ranged from -0.20 to -0.30, p > 0.05, and with the collisions r ranging from 0.20 to 0.30, p > 0.05. No relationship was found between the mobility measures and the DT scores at the 1st annulus.
Table 9.18 The SIPs partial relationship between the DT scores at each annulus with the mobility scores

<table>
<thead>
<tr>
<th></th>
<th>1st annulus</th>
<th>2nd annulus</th>
<th>3rd annulus</th>
<th>4th annulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPWS First visit</td>
<td>$r = -0.04$, $p = 0.37$</td>
<td>$r = -0.10$, $p = 0.95$</td>
<td>$r = -0.30$, $p = 0.03^*$</td>
<td>$r = -0.40$, $p = 0.02^*$</td>
</tr>
<tr>
<td>PPWS Second visit</td>
<td>$r = -0.10$, $p = 0.58$</td>
<td>$r = -0.15$, $p = 0.58$</td>
<td>$r = -0.30$, $p = 0.04^*$</td>
<td>$r = -0.40$, $p = 0.02^*$</td>
</tr>
<tr>
<td>collisions First visit</td>
<td>$r = 0.23$, $p = 0.06$</td>
<td>$r = 0.24$, $p = 0.01^*$</td>
<td>$r = 0.22$, $p = 0.02^*$</td>
<td>$r = 0.30$, $p = 0.01^*$</td>
</tr>
<tr>
<td>collisions Second visit</td>
<td>$r = 0.10$, $p = 0.98$</td>
<td>$r = 0.18$, $p = 0.03^*$</td>
<td>$r = 0.16$, $p = 0.04^*$</td>
<td>$r = 0.30$, $p = 0.02^*$</td>
</tr>
</tbody>
</table>

* indicates statistical significance, $p < 0.05$
9.7 General Discussion

The main aims of this study were to assess the sensitivity, repeatability and validity of the AVA test in real and simulated TV and hemianopic patients. The test was designed to be able to discriminate between participants based on VF, on the scores for different target locations and potentially on the different adaptation levels of the SIPS and TVPs. These characteristics have consequently provided evidence of the sensitivity and validity of the AVA test.

There are some limitations to simulating the field loss in the SIPS which include monocular viewing and the limitation on eye movements. However, this approach allowed the recruitment of a larger number of participants, which would otherwise have been difficult as the targeted conditions causing TV (RP, Usher syndrome and choroideremia) are rare. Recruiting only people with these conditions who were at a stage when mobility was compromised, and who lived in the surrounding area, would have yielded few participants. By adopting this approach it was possible to systematically constrict the VF to different degrees of FoV and, in addition, factors such as adaptation, VA and CS were controlled.

The participants were healthy volunteers who were not familiar with the simulated loss, so FoV was tested in gradually decreasing order to avoid any excessive disorientation or discomfort while doing the required tests. However, a learning effect may have caused performance to improve as the FoV diminished. This would therefore tend to reduce any relationship between the DT scores and the FoV, but this relationship was still found to be significant, possibly because the AVA test takes a short time to conduct, and the participants did not have the chance to gain any relevant experience.

The measure used to assess the participants’ performance in the AVA test was the DT. In each participant the DT that was recorded at each annulus was the median DT of the eight responses from the eight main meridians (discussed in Chapter 8, section 8.1). The DT
reported here is the median and the IQR of the 50 participants' scores. An additional measure of the participants' performance, called the detection efficiency (DE), was used. This was the variation in DT scores (i.e. IQR) within each annulus. The relationship between the DT and DE was explored and a highly significant positive relationship was found between the two measures ($r = 0.60$, $p < 0.05$). This result suggests that the two measures are related but not identical and therefore can be used in further describing the participants' performance. However, when an in-depth analysis was conducted, it was found that the DE demonstrated the same relationships as the DT scores, and did not provide any additional insights into the participants' performance. Therefore, it was decided to use the DT as the main measure of participant performance.

In general, the DT scores in SIPs and TVPs within the same FoV size varied: this difference was previously seen in the mobility course chapter (Chapter 6, section 6.5) and this result suggests that the AVA test can discriminate between different levels of performance. There are also no floor or ceiling effects within each FoV size. This suggests that the scope exists to measurably improve these scores if an effective intervention is introduced e.g. optical aids.

In both the SIPs (Tables 9.3 and 9.4) and TVPs (Tables 9.5 and 9.6) the accuracy of identifying the target location and direction was high, and was not influenced either by eccentricity or (for the SIPs) by the number of visits (i.e. they did not need to learn this ability). This result suggests that the ability to judge the location of obstacles to the sides is not compromised by TV, as long as the obstacles can actually be detected. This result was also found in the participants' median responses to the LVQOL question "How much of a problem do you have with judging the depth or distance of items (e.g. reaching for a glass)?" which was 4 on the scale (5 refers to no problems and 1 refers to great problems). The same result was found in the hemianopes where identifying the target location and direction was
also unaffected by whether the target fell within the seeing or non-seeing field. However, detecting the target location is one issue and reaching and grasping the target is another issue. As has been found previously, restricted FoV affects, to different degrees, the planning and execution of the reach and the grasp of an object (Gonzalez-Alvarez et al., 2007). In the light of this study the participant's subjective response should be interpreted cautiously as it could mean either that they had no problem with reaching and grasping or that they were not aware of this limitation.

In SIPs groups, the DT changed in response to the change in FoV and target eccentricity. As expected, the DT scores increased as the FoV diminished or the targets were more peripheral (Table 9.8; Figures 9.1 and 9.2). Both Friedman and Spearman tests were conducted to explore the relationship between the DT scores with the FoV and the target location. Both tests provided statistical evidence that suggested the FoV and the target location are the main determiners of the DT scores. This result may provide evidence of the sensitivity of the AVA test.

The SIPs’ performance on the AVA test varied between the two visits (Table 9.8), but the changes in DT scores were not statistically significant at the 2nd, 3rd and 4th annulus (Table 9.8). In the Bland-Altman plot the data points are scattered symmetrically below and above the zero difference line which could indicate that the DT scores were sometimes faster on the first visit and sometimes on the second visit (Table 9.11; Figures 9.3 to 9.6). Overall, these results could suggest that the test is repeatable, and there was no learning effect at least at these peripheral locations. This result could support the use of this test on multiple occasions as a tool for assessing the change in performance with optical aids. A more detailed investigation of the learning effect on the AVA test will be discussed in the next chapter; Chapter 10, section 10.3.1. The variation in DT scores could be accounted for by several
factors that are difficult to control, and would influence the participant's performance in this physical task. These factors include: the scanning strategy adopted during the test (and participants may try several different strategies as the test progresses); psychological status; and the amount of attention they paid while doing the task. These outcomes could also indicate that unless an intervention is used, the DT scores would not improve markedly.

The LoA in DT scores, at the third and fourth annulus, which has been found to have a relationship with mobility performance in SIPs 20° and SIPs 15° was approximately ± 3 seconds, in SIPs 10° ± 5 seconds and in SIPs 5° ± 14 seconds (Table 9.11). These LoAs could be used to set limits which would act as an indication of rehabilitation success. This means that professionals who want to prescribe an optical aid can assess its success using the AVA test and may look for a consistent improvement, for example of five seconds, in patients with FoV of 10°. This improvement in score, if achieved, would match the DT scores in patients with 20° FoV (Table 9.8). The optical aids that could enhance the VF to the limit needed could include some form of prism with a power of 20 Δ or 0.50X reversed telescope, but it would be instructive to test whether the AVA performance improved as much as expected from the increase in VF. These optical aids might not ultimately be the most successful for the performance of everyday activities, but testing in the consulting room could be a useful starting point. It should be noted that the variation in the DT scores in SIPs 5° was particularly marked and finding an optical aid that would uniformly improve the DT scores beyond the required level would be questionable.

In the TVP groups, the DT scores were, in general, responsive to the change in FoV and target location, where the DT scores increased with the smaller FoV or for the more peripheral targets (Table 9.12; Figure 9.8). Statistically, however, the DT scores at the 1st annulus do not follow the expected pattern, being longer than the scores at the 2nd annulus.
This result suggests that the participants are facing problems at this particular location, and this might be more related to the TVPs’ acuity and CS loss than simply to the restricted field. The relationship between the DT scores and VA and CS were explored, and no relationship was found at the 2\textsuperscript{nd}, 3\textsuperscript{rd} and 4\textsuperscript{th} annuli. This result was expected as this effect was taken into account when the AVA test was designed. The target size was adjusted to be well above the threshold with maximum contrast to avoid any limitation in VA and CS. However, a moderate but not significant relationship was found between the DT at the 1\textsuperscript{st} annulus and the participants’ VA and CS. This result may support our explanation of why the DT scores at the 1\textsuperscript{st} annulus were longer than those at the 2\textsuperscript{nd} annulus. Based on this finding it was decided to exclude the DT at the 1\textsuperscript{st} annulus in further analysis in the following studies and in the final design of the AVA test. Another reason for this decision was that the DT recorded at the 1\textsuperscript{st} annulus shows several other limitations as follows: it is significantly variable between visits (Table 9.8); it has the weakest relationship with the FoV in the SIPs; it has no relationship with the FoV in the TVPs, and has no relationship with the mobility scores in both the SIPs and the TVPs. This decision reduces the time taken to complete the test by 25% and most importantly maintains the robustness of the AVA test. However, in this study the limitation was isolated at this particular location, and therefore may not affect the validity or the sensitivity of the test.

The relationship between the DT scores and the reported outcomes were investigated. A moderate relationship, but not significant, was found between DT scores at the 3\textsuperscript{rd} and 4\textsuperscript{th} annulus with the IMQ and with the first domain in the LVQOL questionnaire. No relationship was found at the 1\textsuperscript{st} and 2\textsuperscript{nd} annulus, or with the other three sub-domains of the LVQOL. This relationship did not reach a statistically significant level, probably because the majority of the participants reported moderate difficulty in the IMQ (11 out of 20 participants responded 3 on the scale) and moderate problems in the first sub-domain (12 out of 20 participants responded
3 on the scale). This means that our sample was a homogenous group and a huge number of participants would be required to reach the significance level. However, this result may also suggest the importance of the 3rd and 4th annulus in mobility performance. Not finding a relationship with the other three sub-domains of the LVQOL may also provide a further indication of the validity of the AVA test. This result was expected in the hypothesis briefly stated earlier (section 9.1) and in detail (Chapter 5, section 5.1), as the first sub-domain involves several factors that would influence performance on the AVA test and mobility performance, while the other three domains may not have the same influence. Overall, the pattern of the relationships between the AVA test and the reported outcome questionnaires may have supported the validity of the test.

The TVP and SIP performances in the AVA test were compared to explore any differences in DT scores. We had hypothesized that the TVPs would be better performers than the SIPs, because the TVPs have had the opportunity to adapt to the condition and were tested in their habitual states. However, the results obtained contradict our hypothesis. Specifically, the TVPs’ DT scores at the 1st annulus were significantly greater than those of the SIPs, although the reason for this has already been discussed. Other than this difference in DT, no significant difference was found between the TVP and SIP DT scores at the three peripheral locations. This could be because the TVPs were suffering from CS reduction which slows them down. In order to investigate this explanation a future study might be required in which a CS simulation as well as TV simulation in healthy volunteers would be required in order to compare their performance with TVPs’ performance.

The hemianopic patients were tested on the AVA test, and the DT scores were compared in according to the location of the targets: i.e. whether falling in the non-functioning or in the functioning field. The difference in DT scores between the non-functioning and functioning
sides was obvious. The variation found in DT scores indicated that the participant was detecting the target quicker on the functioning side in comparison to the non-functioning side. However, this effect did not reach a statistically significant level when the 1st annulus scores were included. When the 1st annulus scores were removed from the analysis a significant effect was found. This is could be because the 1st annulus scores were highly variable and therefore were masking the VF effect on the DT scores at the rest of the annuli. The ANCOVA, at the three peripheral annuli, showed that the VF defect could explain up to 30% of the variation in the DT scores even with only two participants. Overall, this result may suggest that the AVA test has the potential to be a useful measure in investigating the performance of patients with hemianopia.

In the SIPs, the direct relationship between the DT scores and the mobility scores was highly significant (Table 9.18). The shared variance between the DT scores and PPWS was up to 36% (at the three peripheral annuli), and with collisions was up to 26% (at the three peripheral annuli). The FoV was found in this study and the mobility study to be the main determinant of the participants' performance on the tests, therefore a relationship between the tests was expected. When the FoV was controlled and the relationships between the two measures were explored, the relationship between the DT and the two mobility measures at 1st and 2nd annuli was not significant, yet the relationship at the 3rd and 4th annulus remained significant. Further, the target locations that were found to have a significant relationship with the mobility measure are the 3rd and 4th annuli which are beyond the static FoV of all four FoV sizes. Good performance at these locations on the AVA test requires good scanning ability, and seems to represent a good performance on the mobility course. This means that the participants who had faster DT for the peripheral targets may also have increased ability to be aware of, and avoid, obstacles that are at 20° and 30° from fixation. However, this does not mean that the AVA test would always predict mobility performance. This is because, as
has been discussed previously (Chapter 1, section 1.4; Chapter 6, section 6.3.3 and Chapter 7, section 7.6) there are several factors that are important in creating mobility. These factors include health status, age, adaptation, visual functions (as seen in the TVPs), training, confidence and motivation, and in terms of this study, the SIPs’ sudden change in FoV and the sudden elimination cues could have played a role here.

In the TVPs, a small to moderate relationship was found between the DT at the three peripheral locations (from 2\textsuperscript{nd} to 4\textsuperscript{th} annulus) with both mobility measures. The relationship was less marked than the SIPs relationship and was not significant, but this may be explained by the larger variation in scores for the TVPs (Table 9.14). This may mean that in order to match the relationship strength and reach the significant level found in the SIPs, a much larger sample of TVPs would be needed. Overall, however, this relationship may indicate that the AVA test scores explain some features of mobility performance.

In summary, the AVA test scores were responsive to FoV and target eccentricity in both SIPs and TVPs. This result indicates that the AVA test is a sensitive measure. The AVA test was found to be repeatable, this indicates that an improvement in the DT scores would be unlikely unless an intervention (e.g. optical aid) was introduced. The AVA scores have a significant relationship with the mobility course scores in the SIPs and a moderate relationship in TVPs. This may indicate that the new test is valid. The results obtained from the patients with hemianopia also suggest that the AVA test is a useful measure in another group with VF defects. The AVA test is unique in its design, taking a short time to conduct, and is easily incorporated within a clinic or a lab. Finally, the Assessment of Visual Awareness test shows promise as a clinical measure to test the efficacy of optical aids that are intended to enhance mobility performance in TVPs.
10 Chapter Ten: The Impact of the Learning Effect on the AVA Test and the Mobility Course Scores
10.1 Study Rationale, Aims and Hypothesis

A study was conducted to investigate the learning effect on the AVA test and mobility course scores over a longer period of time than the two visits that the SIPs made in the main study. The aim of this study was to compare the change in scores on the mobility course with the change in scores in the AVA test, in order to find out if one of them is more resistant to the learning factor, which would mean that it is consistent and more reliable in assessing the efficacy of optical aids in TVPs. Although the mobility performance of SIPs showed good repeatability over the two visits (Chapter 7, section 7.5.1), we hypothesized that there would be an improvement in mobility performance due to the learning factor if the test was repeated more often. This is because the test was short (taking few minutes to conduct) and the SIPs were not familiar with field loss. However, if the test was conducted on several visits with the same layout, the participants would be expected to build up relevant experience in dealing with the sudden change in FoV and also in planning their route. On the other hand, the AVA scores might be expected not to change or only minimally change but not significantly so. This is because the AVA test presents the peripheral targets in a random order, and therefore, pre-planning decisions cannot be used here. Our hypothesis is that the AVA test is a more reliable and consistent test than the mobility course.

10.2 Materials and Methods

One participant was recruited to attend a series of visits on six consecutive days. This participant had not been recruited in any other studies, was a healthy volunteer and satisfied the inclusion criteria (Chapter 5, section 5.3.1). The participant was a 33 year old female with VA of 0.00 logMAR in the RE and 1.85 log CS is in the RE. The participant was asked to do the same mobility course, the same AVA test and the VF with the simulators every time she visited our lab.
The AVA test and mobility course that were used in the previous studies were also used in this experiment. Since the aim was to explore the learning effect, the AVA test procedure was the same on each visit, the target sequence was randomised and the layout of the obstacles on the mobility course was the same for each of the six visits. The same simulators that were used in the previous studies were used in this study (Chapter 5, section 5.3). The DT at the 1st annulus was collected at the time of the study, however, due to the reasons presented in the previous chapter (Chapter 9, section 9.7) the responses of 1st annulus were excluded from the analysis.

10.3 Results

All the data collected were used in the analysis. The data collected from both tests were tested for normality. The test showed that data were normally distributed: Kolmogorov-Smirnov, $p > 0.05$, therefore parametric testing was used.

10.3.1 Learning Effect on the AVA Test Scores

The DT scores recorded at each annulus with each simulator varied between visits. There was no indication that these variations in scores are due to learning experience. This is because the scores were not improved with test repetition and sometimes the DT scores at the end of the test were slower than those on the first visit (Table 10.1).
Table 10.1 The DT scores with the four simulators at the three annuli. Each value is the median of eight directions

<table>
<thead>
<tr>
<th></th>
<th>SIP 20°</th>
<th>SIP 15°</th>
<th>SIP 10°</th>
<th>SIP 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit 1</td>
<td>2.99</td>
<td>1.10</td>
<td>4.80</td>
<td>5.47</td>
</tr>
<tr>
<td>Visit 2</td>
<td>1.44</td>
<td>1.94</td>
<td>3.56</td>
<td>7.49</td>
</tr>
<tr>
<td>Visit 3</td>
<td>1.69</td>
<td>3.57</td>
<td>3.34</td>
<td>9.52</td>
</tr>
<tr>
<td>Visit 4</td>
<td>1.51</td>
<td>3.35</td>
<td>3.63</td>
<td>10.80</td>
</tr>
<tr>
<td>Visit 5</td>
<td>2.10</td>
<td>2.45</td>
<td>6.93</td>
<td>9.29</td>
</tr>
<tr>
<td>Visit 6</td>
<td>3.47</td>
<td>3.02</td>
<td>4.08</td>
<td>9.22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>SIP 20°</th>
<th>SIP 15°</th>
<th>SIP 10°</th>
<th>SIP 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit 1</td>
<td>5.22</td>
<td>4.66</td>
<td>8.64</td>
<td>6.92</td>
</tr>
<tr>
<td>Visit 2</td>
<td>4.07</td>
<td>6.22</td>
<td>8.22</td>
<td>8.09</td>
</tr>
<tr>
<td>Visit 3</td>
<td>6.17</td>
<td>5.36</td>
<td>11.91</td>
<td>11.47</td>
</tr>
<tr>
<td>Visit 4</td>
<td>5.39</td>
<td>6.65</td>
<td>6.99</td>
<td>12.67</td>
</tr>
<tr>
<td>Visit 5</td>
<td>3.52</td>
<td>9.99</td>
<td>9.12</td>
<td>14.16</td>
</tr>
<tr>
<td>Visit 6</td>
<td>4.61</td>
<td>7.54</td>
<td>8.20</td>
<td>7.60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>SIP 20°</th>
<th>SIP 15°</th>
<th>SIP 10°</th>
<th>SIP 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit 1</td>
<td>10.21</td>
<td>6.36</td>
<td>10.94</td>
<td>13.10</td>
</tr>
<tr>
<td>Visit 2</td>
<td>7.26</td>
<td>6.36</td>
<td>10.14</td>
<td>9.86</td>
</tr>
<tr>
<td>Visit 3</td>
<td>7.50</td>
<td>7.65</td>
<td>8.94</td>
<td>10.38</td>
</tr>
<tr>
<td>Visit 4</td>
<td>7.14</td>
<td>7.42</td>
<td>9.92</td>
<td>10.26</td>
</tr>
<tr>
<td>Visit 5</td>
<td>7.02</td>
<td>6.34</td>
<td>10.21</td>
<td>10.79</td>
</tr>
<tr>
<td>Visit 6</td>
<td>9.19</td>
<td>9.97</td>
<td>8.54</td>
<td>12.06</td>
</tr>
</tbody>
</table>

A two-way ANCOVA was conducted to investigate the differences in the participant's performance between the six visits at the three annuli. The visits and the target location were the factors used to explore impact on DT scores, while the FoV size was the covariant. The test showed no statistically significant difference between the six visits in the DT scores despite the FoV size or the target location, $F(5, 53) = 1.11$, $p = 0.37$; partial eta squared = 0.09. The partial eta squared value indicates that only 9% of the variance in DT scores could be explained by the learning effect. Further, no significant interaction was found between the
visits as a factor and the target location, $F(10, 53) = 1.15, p = 0.35$; partial eta squared = 0.17. This result confirms that there was no learning effect on the DT scores at any of the target locations.

### 10.3.2 Learning Effect on Mobility Performance

The PPWS scores improved over the six visits across the different FoV sizes (Table 10.2). For instance, the PPWS approximately doubled between the first and sixth visit, in SIP 15° and SIP 5°. The collision scores between the first and sixth visit in SIP 20° and SIP 15° seem to decrease progressively, but are more variable in SIP 10° and SIP 5° (Table 10.2).

<table>
<thead>
<tr>
<th></th>
<th>SIP 20°</th>
<th>SIP 15°</th>
<th>SIP 10°</th>
<th>SIP 5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit 1</td>
<td>PPWS</td>
<td>Collisions</td>
<td>PPWS</td>
<td>Collisions</td>
</tr>
<tr>
<td></td>
<td>27.50</td>
<td>3.00</td>
<td>19.75</td>
<td>2.5</td>
</tr>
<tr>
<td>Visit 2</td>
<td>33.75</td>
<td>2.00</td>
<td>28.75</td>
<td>1.50</td>
</tr>
<tr>
<td>Visit 3</td>
<td>40.50</td>
<td>1.00</td>
<td>30.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Visit 4</td>
<td>36.75</td>
<td>0.50</td>
<td>30.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Visit 5</td>
<td>41.50</td>
<td>0</td>
<td>35.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Visit 6</td>
<td>46.25</td>
<td>0.50</td>
<td>40.75</td>
<td>1.00</td>
</tr>
</tbody>
</table>

A one-way ANCOVA was conducted to investigate the differences in the participant's performance between the six visits while the FoV size was the covariance. There was a statistically significant difference between the six visits in the PPWS scores $F(5, 17) = 37.70, p < 0.0001$; partial eta squared = 0.92. The partial eta squared value suggests that 92% of the variance in PPWS scores could be explained by the learning effect. Further, the learning factor was not found to have an effect on the collision scores, $F(5, 17) = 2.15, p = 0.11$; partial eta squared = 0.40. However, partial eta squared value indicates that 40% of the variance in the collisions could be explained by the learning effect.
10.4 Discussion

This study was conducted to explore the learning effect on both of the objective tests that had been used in this study. One participant was recruited to do this experiment over six visits. Recruiting one participant was a limitation, however the aim was simply to explore how an ordinary participant chosen at random would react to repeating the same test six times. The results obtained from this study provide evidence to support the hypothesis that the learning effect has no impact on the results of the AVA test, but significantly influences those of the mobility course test.

The DT scores at each annulus with the different simulators was observed to vary between visits. No statistical evidence was found to indicate that the learning factor impacted the DT scores positively, where only 9% of the variance in the DT scores could be explained by the learning factor. This result was also found while designing the AVA test, where the participant carried out the same test six times on each of two consecutive days (Chapter 8, section 8.2) and no signs of learning effect were found. However, the variations in DT scores in SIP 5° between the visits were marked. This two-fold variation would make it difficult to judge the efficacy of the optical aid in a single trial in these participants.

The participant’s performance in the mobility task varied over the six visits, where the PPWS across the different FoV had improved by about 100% by the end of the study. Further, the collision scores with the first three simulators showed improvements ranging from 100% to 600%. However, with the SIP 5° the PPWS was improved but not the collisions. The learning effect was found to statistically significantly influence the PPWS but not the collision scores. A large proportion of the variance in both measures was explained by the learning effect (i.e. 92% of the variance in the PPWS and 40% in the collisions). Not finding a significant result in the collision scores could account for the effect of the SIP 5° scores on the overall scores...
as no marked changes were found with time. In order to investigate this assumption the ANCOVA was performed while excluding the SIP 5° collision scores, and a statistically significant impact was found of the learning effect on the collisions. In this second analysis 75% of the variance in the collision scores could be explained by the learning effect.

The participant recruited was a slow walker which may indicate that the participant felt in danger, yet there was a significant change after gaining the relevant experience. Based on this observation, actual changes in real TV patients could be of a different magnitude depending on their confidence and previous experience.

In conclusion, there was no significant impact of the learning effect on AVA test scores, whereas a significant influence was found in the mobility task. This result may suggest that the AVA test is consistent and potentially reliable enough to assess rehabilitation success in TV patients.
Chapter Eleven: The Role of the AVA Test in Predicting the Impact of Different Forms of Fresnel Prism on the TVPs Performance
11.1 Aims and Hypothesis of the Study

The performance of the TVPs in the AVA and mobility tests when trying different forms of prisms for both short and long periods of time was investigated. It was hoped that participants could be classified, based on their scores in the IMQ, into good and poor performers in their everyday mobility, and that each group would respond differently to aids (hypothesis 6 and 9; Chapter 5, section 5.1). However, as there was no difference between participants’ scores in the IMQ, as discussed in Chapter 9, this hypothesis could not be explored. The aim is to determine the efficacy of the prism for each TV participant, and the hypothesis is that the AVA test will be able to identify improvement over the short-term and therefore predict rehabilitation success in the long-term. Such a result would indicate that the AVA test could be used in assessing optical aid efficacy as it is reliable.

The TVPs were expected to vary in terms of adopting or rejecting the prism as a mobility aid. This is because some participants develop compensatory strategies (i.e. effective coordination of eye and head movements), which lead to a much larger dynamic VF (i.e. the capability to become aware of a peripheral stimulus and at the same time realise there is an object in the foveal area), and they may not benefit from the prism because it would interfere with their compensatory strategies. On the other hand, some TVPs could find the prism helpful in improving their performance as they are able to incorporate the use of the prism within their compensatory strategies. The aim was that the AVA scores are expected to provide an indication of the potential prism efficacy for each participant by finding a marked improvement in DT. These participants would show better mobility performance after a period of time. This time would be needed to adapt to the change in object location caused by a prism. On the other hand, no marked improvement in the AVA test scores would be found in participants for whom the prism interfered with their compensatory strategies. This result would indicate that the prism would not be helpful in improving mobility performance.
The participants were also assessed in a further visit after trying the prisms for a longer period of time (a few weeks or months). The long-term results were expected to show: 1) maintained improvement in DT in those who showed an improvement in the previous visit, and 2) improvement in the mobility course scores in comparison to the previous visit, as a result of adaptation. This result would also be supported by assessing subjective response, including verbal informal feedback and formal structured feedback based on the IMQ and LVQOL scores. For those participants who did not show an improvement in the AVA test score on their second visit, their result on the mobility course would be expected to be the same as the first visit.

11.2 Materials and Methods

The participants in this study were the same 20 TVPs whose mobility course results are reported in Chapter 7 and AVA test results presented in Chapter 9. After performing these tests the participants were asked to repeat both of them while wearing the prisms. The AVA test design and scoring methods described in Chapters 8 and 9 were used in this chapter. The DT scores at the four annuli were collected with/out the prism, however, for the reasons set out in Chapter 9, the DT scores at the 1st annulus are excluded. The mobility course design and scores (i.e. PPWS and collisions) described in Chapters 6 and 7 were used in this study.

The prisms used in this study were a partial aperture prism and the Tri-field prism, both of which were discussed in Chapter 2, sections 2.2 and 2.2.2. The type of prism chosen for each participant was selected in alternating order. Briefly, the partial prism has no effect on the primary position of gaze, therefore the prism does not expand the residual VF, although when a participant makes an eye movement to view through any of the surrounding prisms, the image is relocated more centrally. The partial aperture prism was created using a stick-on Fresnel prism, which was used in previous studies (e.g. Somani et al. (2006)). The power
chosen was 20 Δ and this provides about 10° enhancement. This prism power was used by Hoppe and Perlin (1993) and Somani et al. (2006). The prism was fitted binocularly around the visual axis (about 2mm from the limbus) in the temporal, nasal and lower part of the spectacle lens (Figure 11.1). This fitting location was chosen to allow a sufficient channel of prism-free area not to interfere with the central vision, which is crucial in terms of VA and for any adopted compensatory strategies. The prisms were placed with the base toward the edge of the lens. The participants were informed that the prisms should be occasionally looked through but were not for constant viewing while walking due to the displaced image. They were asked to use them as motorist would use their rear or side view mirrors, which means that they should look through the prism frequently in order to increase their awareness of the surrounding areas, yet not continuously.

![Figure 11.1 The partial aperture prism used in the study](image)

The segment Fresnel prism was fitted around the participants' visual axis. The Tri-field was designed by Woods and Peli (2002) to expand the horizontal VF. The prism consists of two apex-to-apex prisms mounted in front of one eye that vertically bisect the pupil on primary gaze, and a conventional spectacle lens was used in front of the other eye (Fig. 11.2). Woods et al. (2002, 2010a) suggested that the Tri-field provides VF expansion but that this will create visual confusion (two objects with the same visual direction will be perceived). The
Tri-field prism segments were formed from Fresnel prisms and were fitted over the eye with poorer VA or with the smaller VF size. This fitting procedure was the one proposed by Woods and co-workers (2010a). The method used in this study to calculate the prism power, and the VF measurement procedure with the Tri-field prism are described in Appendix Three.

Figure 11.2 Right eye and left eye Tri-field prisms. Left: the Tri-field prism is fitted over the right eye where the prisms consist of two prisms fitted apex-to-apex to vertically bisect the central gaze. Right: the image shift that the prism produces.

Both prism types were fitted over the TVPs’ spectacles (e.g. single vision with distance prescription). If the participant did not have a pair of glasses, their refraction was assessed and if there was an improvement in the VA, new glasses were prescribed and a second visit was scheduled. However, if there was no improvement noticed in the VA, a pair of glasses with clear plano lenses was given to the participant. The participants were asked to wear the prisms as much as possible during the period of the study. Further, they were informed that the prisms were designed as mobility aids, and should only be used when walking and not when performing other tasks that do not involve moving about, such as reading or watching TV.

After fitting the prism, the intended enhancement was checked by asking the participants to look through the prisms and note any shift in the location of peripheral objects. In the case of the Tri-field, the VF was measured to make sure that there were three separate VF areas and no diplopia. Then the participant was escorted outside the lab for a short walk along a quiet corridor in order to familiarize them with the view through the prisms. The participants were
asked to pay attention to doorframes, chairs and the location of the walls. Then the participants were given a half hour break and were asked to try to walk while wearing the prisms inside and outside the building in order to get used to the view through the prisms. They were asked to walk up and down the stairs, but to use the handrails. Part of this procedure was adapted from Woods et al. (2010a).

The visit routine did not follow the plan initially proposed in the methodology chapter (Chapter 5, section 5.4.3). In the methodology chapter, three visits were planned, each to take place on a different day. However, the first two visits were combined due to difficulties with travelling distance (the majority of the participants came from outside Manchester and some of them were staying overnight), companion arrangements, participants’ convenience and personal schedules. The visit was split into two parts with a break of 30 minutes to 1 hour between them, although the results will refer to these as two separate visits. In Visit 1 the visual function measures and QoL responses were collected and the AVA and mobility tests were performed without using any optical aids. In Visit 2, the VF was repeated, the AVA and mobility tests were performed after trying the optical aid for 30 minutes. In Visit 3, the TVPs' verbal feedback and their responses to questions based on the IMQ and LVQOL questionnaire were collected. The AVA and mobility course tests were then repeated with the participants wearing the prisms.

The participants' visual functions were measured with the same tests used in Chapters 7 and 9. The VA was measured with logMAR VA ETDRS chart "2000" (Precision Vision, La Salle IL 61301, US). The CS was measured with Pelli-Robson CS chart at one metre with overhead illumination (approximately 85 cd/m²) (Metropia Ltd., UK; distributed by Clement Clarke Intl) (Pelli et al., 1988). The VF was measured using a Bjerrum screen and the method used to calculated the VF size is described in Chapter 5, section 5.3.2.
11.3 Participant Characteristics

The TVPs were patients with RP or Usher syndrome. The 20 TVPs, consisting of 9 men and 11 women, had all done the AVA and mobility test on the first visit. The TVPs’ VA and CS without the prism are listed in Table 11.2. The prism type and power for the 20 TVPs are listed in Table 11.2. The VA and VF while wearing the partial aperture prism were not collected because the wearer did not view through the prism in the primary position, so the VA and VF did not change. The VA with the Tri-field prism also remained at the same level of VA as measured without the prism, presumably because the prism was fitted in front of one eye while the better eye remained in its habitual state. The VF expansion was measured based on the definition proposed by Woods and colleagues (2010a), which is "the distance between the leftmost edge of the left expanded area and the rightmost edge of the right expanded area" (Figure 11.3). A VF expansion with the Tri-field was demonstrated for all participants, the median expansion was 40° (ranging from 19° to 56°) (Table 11.2).

About half of the participants used a long cane when travelling (11 out of 20 participants) (Table 11.2). Ten of these 11 participants had received mobility training, however, in most cases the training was short, extending only over a few hours and concentrating on the best approach to use with the long cane; however TVP 8 had had multiple sessions over six weeks and TVP 17 had had multiple sessions over four days. None of the participants had used any optical aids for navigation.
In Figure 11.3, the expansion caused by the prisms is indicated by the two dashed areas to the left and right of fixation. "The distance between the leftmost edge of the left expanded area and the rightmost edge of the right expanded area (shown by the arrow) was defined as the expanded visual field". The figure is adapted from Woods et al. (2010a).
11.4 Results

11.4.1 Direction Accuracy

The mean percentages of correct identification of the target location and direction in the AVA test are listed in Table 11.1. The accuracy in identifying target location did reduce with the prism (Visit 2) compared to without (Visit 1). The differences in the scores was up to 20%, but this difference did not invalidate the scores as the target direction was correctly perceived. This means that all the DT scores were included in the analysis procedure. The accuracy of the target direction did not vary between with (Visit 2) and without (Visit 1) the prism (Table 11.1). The Chi-square test for independence was conducted to explore the impact of the prisms on the accuracy of identifying the target location and target direction. Regardless of the FoV size and the type of prism, the test showed that there is no statistically significant impact of the prism on either accuracy measures ($p > 0.05$). The mean accuracy of the target location in Visit 3 was no different to the accuracy scores in Visit 2 (Table 11.1).
Table 11.1 The mean percentage accuracy of reporting the target position and direction in the three TVPs groups

<table>
<thead>
<tr>
<th>Mean accuracy</th>
<th>TVPs 20° (n=7)</th>
<th>TVPs 10° (n=8)</th>
<th>TVPs 5° (n=5)</th>
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<tbody>
<tr>
<td>Target Location</td>
<td>Without/ with prism (visit 3)</td>
<td>Without/ with prism (visit 3)</td>
<td>Without/ with prism (visit 3)</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>99% / 95% (97%)</td>
<td>99% / 88% (87%)</td>
<td>98% / 83% (81%)</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>99% / 87% (84%)</td>
<td>99% / 79% (75%)</td>
<td>99% / 87% (88%)</td>
</tr>
<tr>
<td>4th annulus</td>
<td>99% / 90% (93%)</td>
<td>99% / 91% (98%)</td>
<td>99% / 80% (81%)</td>
</tr>
<tr>
<td>Target Direction</td>
<td>Without/ with prism (visit 3)</td>
<td>Without/ with prism (visit 3)</td>
<td>Without/ with prism (visit 3)</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>99% / 95% (98%)</td>
<td>100% / 100% (99%)</td>
<td>97% / 97% (100%)</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>99% / 99% (99%)</td>
<td>100% / 100% (100%)</td>
<td>99% / 100% (99%)</td>
</tr>
<tr>
<td>4th annulus</td>
<td>100% / 100% (99%)</td>
<td>99% / 98% (99%)</td>
<td>100% / 100% (100%)</td>
</tr>
</tbody>
</table>
11.4.2 The Impact of Prisms on DT

It was possible that grouping participants either based on their FoV or on the type of prism worn and then averaging their scores would mask any improvement, as the participants differ in their visual and non-visual characteristics which include VA, CS, VF, adaptation, mobility training and using the long cane. Further, the professional using the AVA test in a clinic or lab to determine the efficacy of an optical aid for a particular patient would not use a statistical package. Therefore, each participant was considered individually in addition to being grouped based on performance and prism type. In this study, improvement was considered to be marked and was expected to have an effect on mobility performance if it was an improvement of 40% or 50% from the individual baseline scores without aid. The TVP ID number reported here is for identification only and does not reflect the order in which the TVPs were recruited.

A total of nine participants agreed to take home the prism, in its different forms, and use it over an extended period. The median of the separation between the second and third visit was four weeks (the range was three to twelve weeks). The participants reported that they used the prism every day, usually for between one and two hours a day. Only TVP 7 used the Tri-field prism for a longer period of time every day; this was three to four hours a day but not continuously.

Unexpectedly, neither the Tri-field prism nor the partial aperture prism improved the participants’ performance in either the AVA test or in the mobility course, except in one case. Interestingly, the scores in the AVA test suggested that the prisms did not provide the participants with any additional information to enhance their mobility performance in the course. Further, the scores after the extended wearing period were in agreement with the results obtained in the AVA test scores on the second visit (with aid).
Of the fifteen TVPs in the 20° and 10° groups, eight wore the partial aperture prism (TVPs 1-5 and 8-10) and seven wore the Tri-field prism (TVPs 6 and 7 and 11-15) (Table 11.2). Of the eight participants wearing the partial aperture, three of them (TVP 1, TVP 8 and TVP 10) scored longer DTs at two out of the three annuli and four participants scored the same DT scores at two annuli out of the three. As expected, mobility performance was worse in the majority of the participants with the prism (TVPs 1, 3, 5, 8, 9, and 10); they were slower and scored more collisions. TVP 2 tried to walk faster with aid, yet scored more collisions (two more collisions). This seems to be due to his high expectation level of the benefits of the prism. Interestingly, TVP 4’s performance showed marked improvement in the DT scores at the three annuli (by 50%). TVP 4’s PPWS increased by 11%, yet the collisions also increased (from 0.50 to 1). In the seven participants who tried the Tri-field prism, four of them (TVP 6, 7, 11 and 14) scored longer DTs in at least two out of the three annuli and the other three participants (TVP 12, 13, 15) scored the same DTs in at least two annuli. The majority of the participants were slower with the prism. In terms of the collision scores: three participants scored more collisions and four participants scored fewer collisions (Table 11.2).

In the TVP 20° and 10° group, five participants tried the partial aperture prism (TVPs 1, 2, 4, 8 and 9) and two participants (TVPs 7 and 15) used the Tri-field prism for an extended time (Table 11.2). As predicted, by the AVA test in the second visit, TVP 4 maintained her marked improvement in the AVA test (i.e. improvement in DT by 50%). Further, the PPWS was better on the third visit (PPWS = 70% compared to 49% on the first visit) and the collision scores had improved (scored no collisions) (Table 11.2). On the other hand, the rest of the participants who tried the prism for an extended time did not record scores that were significantly different from those on Visit 2. In detail, TVPs 1, 2 and 8 on their third visit scored DTs longer than those on Visit 2, while TVP 9 scored the same DT as on Visit 2. In those four participants no sign of obvious improvements in mobility performance were
recorded. The PPWS was, generally, lower than on Visit 2 and more collisions took place. The two participants (TVPs 7 and 15) who wore the Tri-field did not show any improvement in their DT scores in comparison to Visit 2. Their mobility scores were also the same as on Visit 2 (Table 11.2).

In the TVPs 5° group, TVPs 16 and 17 were tested with the partial aperture prism and TVPs 18-20 tried the Tri-field prism (Table 11.2). TVP 16 scored shorter DTs at two out of the three annuli (by 1.50 seconds and by about 20 seconds, respectively). TVP 17 scored longer DTs at two out of the three annuli, yet this change was not markedly different from his baseline scores (by 3 seconds). The two participants scored the same PPWS with the prism. TVP 16 scored more collisions and TVP 17 scored fewer collisions with the prism. TVPs 18-20 wore the Tri-field prism, and generally these three participants scored shorter DTs with the prism; yet this change was marked only in one participants (TVP 18). The PPWS was the same for TVPs 18 and 19 and was lower in TVP 20. The three participants scored more collisions with the Tri-field prism.

TVPs 17 and 18 agreed to take home the partial aperture prism and Tri-field, respectively, for a longer period of time (Table 11.2). It was not surprising that the participants' performances in both objective tests were not markedly better than their scores on Visit 2 after using the aid for an extended period. This is because the participants' DT scores on the second visit did not show any sign of a marked improvement. On Visit 3, the DTs of these two participants were sometimes slightly shorter, longer or recorded no change at the three annuli. PPWS did not change in TVP 17 and was lower in TVP 18.
Table 11.2 The TVPs background data and their scores in the AVA test and mobility test before and after using the prism for a short and long period of time

<table>
<thead>
<tr>
<th>ID. reference</th>
<th>VF</th>
<th>VA</th>
<th>CS</th>
<th>Prism Type</th>
<th>VF With prism</th>
<th>Long cane/ O&amp;M training</th>
<th>DT 2nd annulus</th>
<th>DT 3rd annulus</th>
<th>DT 4th annulus</th>
<th>PPWS</th>
<th>Collisions</th>
</tr>
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<tbody>
<tr>
<td><strong>TVPs 20°</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>TVP 1 Visit 1</td>
<td>19°</td>
<td>0.30</td>
<td>1.55</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>no/no</td>
<td>1.11</td>
<td>3.11</td>
<td>6.65</td>
<td>65.25</td>
<td>0.50</td>
</tr>
<tr>
<td>TVP 1 Visit 2</td>
<td>19°</td>
<td>0.30</td>
<td>1.50</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>yes/yes</td>
<td>1.53</td>
<td>5.13</td>
<td>4.28</td>
<td>41.25</td>
<td>1</td>
</tr>
<tr>
<td>TVP 1 Visit 3</td>
<td>22°</td>
<td>0.14</td>
<td>1.80</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>no/no</td>
<td>3.09</td>
<td>7.57</td>
<td>7.98</td>
<td>68.50</td>
<td>0</td>
</tr>
<tr>
<td>TVP 2 Visit 1</td>
<td>21°</td>
<td>0.10</td>
<td>1.75</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>yes/no</td>
<td>2.03</td>
<td>3.31</td>
<td>5.31</td>
<td>49.00</td>
<td>0.50</td>
</tr>
<tr>
<td>TVP 2 Visit 2</td>
<td>18°</td>
<td>0.40</td>
<td>1.65</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>no/no</td>
<td>14.43</td>
<td>20.64</td>
<td>15.67</td>
<td>54</td>
<td>1.5</td>
</tr>
<tr>
<td>TVP 2 Visit 3</td>
<td>19°</td>
<td>0.40</td>
<td>1.60</td>
<td>Tri-field 40 (\Delta)</td>
<td>-</td>
<td>no/no</td>
<td>1.16</td>
<td>2.65</td>
<td>2.67</td>
<td>61.75</td>
<td>0</td>
</tr>
<tr>
<td>TVP 3 Visit 1</td>
<td>12°</td>
<td>0.20</td>
<td>1.35</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>no/no</td>
<td>3.05</td>
<td>3.02</td>
<td>4.29</td>
<td>52</td>
<td>0</td>
</tr>
<tr>
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<td>12°</td>
<td>0.16</td>
<td>1.35</td>
<td>Tri-field 40 (\Delta)</td>
<td>-</td>
<td>no/no</td>
<td>2.99</td>
<td>4.13</td>
<td>5.36</td>
<td>44.75</td>
<td>0.50</td>
</tr>
<tr>
<td>TVP 4 Visit 1</td>
<td>12°</td>
<td>-0.02</td>
<td>1.65</td>
<td>Tri-field 25 (\Delta)</td>
<td>-</td>
<td>yes/yes</td>
<td>2.23</td>
<td>5.55</td>
<td>9.04</td>
<td>42.25</td>
<td>4</td>
</tr>
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<td>TVP 4 Visit 2</td>
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<td>-0.14</td>
<td>1.85</td>
<td>Tri-field 30 (\Delta)</td>
<td>-</td>
<td>yes/yes</td>
<td>2.19</td>
<td>4.95</td>
<td>5.35</td>
<td>45.75</td>
<td>1.50</td>
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<tr>
<td>TVP 5 Visit 1</td>
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<td>0.40</td>
<td>0.60</td>
<td>Tri-field 40 (\Delta)</td>
<td>51°</td>
<td>yes/yes</td>
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<td>11.91</td>
<td>14.76</td>
<td>37.50</td>
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<td>TVP 5 Visit 2</td>
<td>12°</td>
<td>0.00</td>
<td>1.70</td>
<td>Tri-field 25 (\Delta)</td>
<td>48°</td>
<td>no/no</td>
<td>2.95</td>
<td>6.72</td>
<td>5.89</td>
<td>32.50</td>
<td>0.50</td>
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<td><strong>TVPs 10°</strong></td>
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<td>8°</td>
<td>0.30</td>
<td>1.60</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>yes/yes</td>
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<td>4.60</td>
<td>9.83</td>
<td>69</td>
<td>1</td>
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<td>TVP 6 Visit 2</td>
<td>13°</td>
<td>0.30</td>
<td>1.05</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>yes/yes</td>
<td>2.64</td>
<td>6.60</td>
<td>11.59</td>
<td>60.50</td>
<td>0</td>
</tr>
<tr>
<td>TVP 7 Visit 1</td>
<td>12°</td>
<td>0.20</td>
<td>1.35</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>no/no</td>
<td>3.05</td>
<td>3.02</td>
<td>4.29</td>
<td>52</td>
<td>0</td>
</tr>
<tr>
<td>TVP 7 Visit 2</td>
<td>12°</td>
<td>0.16</td>
<td>1.35</td>
<td>Tri-field 40 (\Delta)</td>
<td>39°</td>
<td>no/no</td>
<td>1.78</td>
<td>5.66</td>
<td>6.64</td>
<td>74</td>
<td>4</td>
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<tr>
<td>TVP 8 Visit 1</td>
<td>12°</td>
<td>-0.02</td>
<td>1.65</td>
<td>Tri-field 25 (\Delta)</td>
<td>46°</td>
<td>yes/yes</td>
<td>2.23</td>
<td>5.55</td>
<td>9.04</td>
<td>42.25</td>
<td>4</td>
</tr>
<tr>
<td>TVP 8 Visit 2</td>
<td>12°</td>
<td>-0.14</td>
<td>1.85</td>
<td>Tri-field 30 (\Delta)</td>
<td>42°</td>
<td>yes/yes</td>
<td>2.19</td>
<td>4.95</td>
<td>5.35</td>
<td>45.75</td>
<td>1.50</td>
</tr>
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<td>TVP 9 Visit 1</td>
<td>12°</td>
<td>0.20</td>
<td>1.60</td>
<td>Tri-field 35 (\Delta)</td>
<td>48°</td>
<td>no/no</td>
<td>1.19</td>
<td>2.38</td>
<td>5.80</td>
<td>83.50</td>
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<td>0.00</td>
<td>1.70</td>
<td>Tri-field 25 (\Delta)</td>
<td>30°</td>
<td>no/no</td>
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<td>5.98</td>
<td>4.74</td>
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<tr>
<td><strong>TVPs 5°</strong></td>
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<tr>
<td>TVP 10 Visit 1</td>
<td>5°</td>
<td>0.10</td>
<td>1.65</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
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<td>17.97</td>
<td>10.27</td>
<td>38.43</td>
<td>32.50</td>
<td>0.50</td>
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<td>TVP 10 Visit 2</td>
<td>4°</td>
<td>0.16</td>
<td>1.50</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>yes/yes</td>
<td>3.63</td>
<td>18.95</td>
<td>46.62</td>
<td>23</td>
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<td>6°</td>
<td>0.40</td>
<td>1.05</td>
<td>Tri-field 25 (\Delta)</td>
<td>21°</td>
<td>yes/yes</td>
<td>3.12</td>
<td>6.81</td>
<td>5.98</td>
<td>66</td>
<td>0.50</td>
</tr>
<tr>
<td>TVP 11 Visit 2</td>
<td>6°</td>
<td>-0.02</td>
<td>1.65</td>
<td>Tri-field 20 (\Delta)</td>
<td>19°</td>
<td>no/no</td>
<td>5.07</td>
<td>11.31</td>
<td>11.68</td>
<td>38</td>
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</tr>
<tr>
<td>TVP 12 Visit 1</td>
<td>6°</td>
<td>0.22</td>
<td>1.05</td>
<td>Tri-field 15 (\Delta)</td>
<td>23°</td>
<td>yes/yes</td>
<td>15.52</td>
<td>29.16</td>
<td>19.99</td>
<td>20.50</td>
<td>2</td>
</tr>
<tr>
<td>TVP 12 Visit 2</td>
<td>5°</td>
<td>0.10</td>
<td>1.65</td>
<td>Aperture 20 (\Delta)</td>
<td>-</td>
<td>yes/yes</td>
<td>18.94</td>
<td>22.72</td>
<td>15.40</td>
<td>15.75</td>
<td>4</td>
</tr>
</tbody>
</table>

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11.4.3 The TVPs Reported Outcome after Using the Prisms

The participants' verbal informal feedback and their subjective responses to the questions in the IMQ and LVQOL questionnaire (the same questionnaires used in Chapters 7 and 9) were collected after using the partial aperture prism and the Tri-field prism for an extended period. Not all the items in the IMQ or in the LVQOL questionnaire were answered on the third visit either because a particular situation in the IMQ was not applicable, due to not wearing the glasses for that activity, or not trying them outside the house (even though they were asked to try to wear them inside and outside the house), or because some of the items in the LVQOL questionnaire were not relevant to mobility (i.e. the items in the adjustment sub-domain) or involved a task not performed while wearing the glasses (i.e. the items in the reading sub-domain). Therefore, the participants’ responses in the IMQ and LVQOL were used as structured formal subjective responses (will be referred to as formal feedback) and a brief description of their response on certain tasks will be reported. The IMQ items were divided into three main themes:

1. walking about: walking in familiar areas, walking in unfamiliar areas and moving about at home;
2. steps and curbs: detecting ascending stairwells, detecting descending stairwells, walking up steps, walking down steps, stepping onto curbs and stepping off curbs;
3. avoiding obstacles: avoiding bumping into: people, walls, head-height objects, shoulder-height objects, waist-height objects, knee-height objects and low-lying objects and, finally, being aware of another person's presence.

The items that will be reported from the LVQOL questionnaire were the items in the first domain and the ADL. These items include: seeing moving objects, judging the depth or distance of items, seeing steps or curbs, getting around outdoors, crossing a road with traffic
and, finally, everyday activities. The participants were asked to rate the difficulty or problem they have with these activities while wearing the aid.

In general, both the informal and formal feedback showed that the participants were not very satisfied with the use of both prisms. They reported that the prisms were not producing the expected performance enhancement. However, the feeling was less negative with the partial aperture prism than with the Tri-field prism.

In detail, the informal feedback of TVPs 1, 2, 8, 9 and 17 (the first two participants had FoV of 19° and 21°, the third and fourth had 8° and 13° and the fifth participant had 4° FoV) was collected after trying the partial aperture prism. The informal feedback included reporting more awareness of objects to the sides, but the overall impression was that there was no marked improvement in performance with the prism. The participants reported fear of walking outside alone while wearing the prism, criticized the poor image quality, and one of them was concerned about the appearance of the prism. The formal feedback was in line with the results of the participants' performance in the AVA and mobility course tests. Generally, the five participants did not report any improvement due to using the prism and found the prism more of a hindrance than a help. The changes in scores showed either more difficulty or no change in performing certain tasks. For example, TVP 1, in the IMQ, reported that moving around at home was more difficult while wearing the prism (this had changed from 1 (no difficulty) to 5 (extreme difficulty)) (Table 11.3). TVP 1’s scores in the second and third themes were the same, and the difficulty ranking was increased by one step (Table 11.3). The same result was found in the other four participants, where the IMQ scores had not changed markedly (one step on the scale), but were in the direction of having more difficulty in the different situations (Table 11.3). TVPs 1, 8, 9 and 17 scores in the LVQOL questionnaire did not change in the first domain between visits (ranging from 2 to 4 on the scale), and no
change was found when reporting the problems they had in everyday activities (3 on the scale). TVP 2 reported more problems in doing the tasks in the first domain and in everyday activities. She reported having more problems in these situations with the prism than without the prism (the scores changed from 3 or 4 to 1, indicating great difficulty).

The informal feedback of TVP 4 (FoV 21°) was that she felt positive about the aid and reported that the prism was helping her to see objects to the sides, especially steps and curbs (this highlights the importance of the inferior part of the VF). She also reported that the prism was practical inside the house but not in a crowd as it caused confusion. She did not want to use the aperture prism permanently as she used a cane (she had not had any training), and disliked the appearance of the spectacles. This participant's formal feedback after trying the partial aperture prism indicated minimal change when answering the IMQ questions, although there was a decrease in difficulty (Table 11.3). The participant's scores in the first domain of the LVQOL questionnaire did not change between the first and the third visit; her problems ranked from 5 (no problem) to 3 (moderate). Her problems with everyday activities were rated 4 on the scale on both visits.

Three participants, TVPs 7, 15 and 18 whose FoVs were 19°, 9° and 6° respectively, tried the Tri-field for a period of time and their feedback was collected. In general, they agreed that the Tri-field prism was a good concept and they grasped the idea of the multiple images. They reported that they were sometimes aware of obstacles to the sides, but could find no satisfactory benefits to offset the problems they experienced with the prism’s multiple images. These were confusion leading to disorientation (especially in crowds), headaches, eyestrain, discomfort, dizziness and occasionally diplopia. Their formal feedback indicated that the IMQ scores had changed for the different situations as they now found it more difficult to perform the different tasks (Table 11.3). These three TVPs, in the LVQOL
questionnaire, reported either no changes or changes towards having more problems (i.e. scores moving from 3 to 4 or from 2 to 4 on the scale). In general the three participants had moderate problems in tasks including daily activities (Table 11.3).
Table 11.3 Changes in IMQ scores on the third visit, after using both prisms for a period of time

<table>
<thead>
<tr>
<th></th>
<th>Partial Prism</th>
<th>Tri-field Prism</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theme 1</td>
<td>Theme 2</td>
</tr>
<tr>
<td>TVP 1</td>
<td>worse, changed from 1 to 5</td>
<td>no change at 5</td>
</tr>
<tr>
<td></td>
<td>Unfamiliar:</td>
<td></td>
</tr>
<tr>
<td>TVP 2</td>
<td>worse, changed from 1 to 4</td>
<td>worse, changed from 3 to 4</td>
</tr>
<tr>
<td></td>
<td>Unfamiliar:</td>
<td></td>
</tr>
<tr>
<td>TVP 4</td>
<td>improved, changed from 3 to 2</td>
<td>improved, changed from 3 or 4 to 1</td>
</tr>
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<td>Unfamiliar:</td>
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<td>no change at 5</td>
<td>no change at 5</td>
</tr>
<tr>
<td></td>
<td>Unfamiliar:</td>
<td></td>
</tr>
<tr>
<td>TVP 9</td>
<td>no change at 1 to 2</td>
<td>worse, changed from 3 to 4</td>
</tr>
<tr>
<td></td>
<td>Unfamiliar:</td>
<td></td>
</tr>
<tr>
<td>TVP 17</td>
<td>worse, changed from 3 to 4</td>
<td>worse, changed from 2 or 3 to 3 or 4</td>
</tr>
<tr>
<td></td>
<td>Unfamiliar:</td>
<td></td>
</tr>
</tbody>
</table>

**Theme 1**: walking about: walking in familiar areas, walking in unfamiliar areas and moving about in home; **Theme 2**: steps and curbs: detecting ascending stairwells, detecting descending stairwells, walking up steps, walking down steps, stepping onto curbs and stepping off curbs and **Theme 3**: avoiding obstacles: avoiding bumping into: people, walls, head-height objects, shoulder-height objects, waist-height objects, knee-height objects and low-lying objects and, finally, being aware of another person's presence. The IMQ scale: 1 represent no difficulty and 5 represent extreme difficulty. The LVQOL grading: 5 refer to none and 1 refer to great problem.
11.5 General Discussion

In this study the ability of the AVA test in predicting the efficacy of two types of prisms was investigated. Performance with the prisms was assessed based on performance in the two objective measures after using the prism over a short and an extended period of time. In addition, the participant's informal and formal feedback was collected after trying the aid for the extended time.

Because of the difficulties in scheduling visits, the participants did the objective tests with and without the aids on the same day. The participants might have learned from their first exposure to the objective tests and if that was true, any improvement in their scores might have been due to familiarity, rather than any enhancement caused by the prisms. However, this was not expected, as it was found previously in Chapter 10 and in Chapter 8 that the AVA test is consistent and not influenced by any learning effect. The mobility course could be influenced by a learning effect, however this would not be marked due to the fact that the course takes only two to three minutes to complete. This is unlikely to be sufficient time to develop a strategy other than the compensatory strategies that were already used in their everyday activities. Further, in general, the mobility scores recorded in this study did not improve over the short-term, which excludes any learning effect.

The participants recruited were a homogenous group in terms of their response to the QoL questionnaires on the first visit. This result did not enable us to divide our participants into two groups (i.e. good performer and poor performer in everyday activities) nor to relate that to AVA and mobility scores and then predict any long-term success. Instead, we tried to look at each participant individually or at a group of participants whose performances were similar. This approach compares to how a clinician in his/her clinic would work in trying to decide whether or not to recommend a particular device for a particular TV patient.
In the discussion in Chapter 9 it was proposed that the improvements in DT which suggest that the optical aid is effectively enhancing the participants' performance are: improvement by three seconds in participants with FoV of 20°, five seconds with 10° and 14 seconds with 5°. In this study, deciding that a marked improvement in DT scores was recorded was not based on our previous suggestions. This is because we discovered that it was not possible, as some participants, for example TVP 6, scored a DT shorter than the suggested limit, indicating that recording an improvement by these limits was not feasible. Therefore, the improvement in DT scores was judged based on individual DT responses rather than on a generalization from group performance. However, this does not mean it is entirely based on clinician judgment but the improvement should be obvious, which means an improvement of 40% or 50% from the individual baseline scores is required.

In general, the results obtained from this study support our statement that the AVA test is reliable in investigating the efficacy of optical aids for TV patients. In the participants who showed no marked improvement in the AVA test with the prism, their mobility performance was worse and did not improve over a period of time while their DT on the third visit was similar to their scores on the second visit. Further, the AVA test clearly indicated the participants who benefited from the prism in the short-term, and their long-term scores confirmed their short-term scores in the AVA test.

The findings obtained from this study suggest that the potential benefits of both prisms might have been overestimated. Finding no improvement with the partial aperture prism may have been because the aid works by shifting the image rather than expanding the VF. This means that the participants had to make eye movements into the prism in order to notice the targets falling outside their FoV. However, if the participants were not used to making repeated eye movements outside their functioning field, then they were unlikely to benefit from the partial
aperture prism. Alternatively, if the participants had already adopted effective eye movements, placing the prism within their dynamic field would interfere with their strategy and therefore would negatively impact their performance. Not finding an improvement with the Tri-field is probably due to different reasons. The Tri-field works by expanding the VF, but there is a trade off in confusion. This means that sometimes three images are perceived simultaneously and yet the user does not know the true directions of these images. This confusion is possibly the reason why this prism was not found to enhance the participants’ performance. This suggestion is supported by the participants’ informal feedback, in which they reported confusion and dizziness while using the Tri-field.

In terms of discussing the data obtained from this study, the accuracy of identifying the target direction was not found to be influenced by the prism. This result was expected as the prism does not cause a crossover effect, which means that a target on the nasal side would not be shifted to the temporal side. The accuracy of the target location with/without the prism was fairly high. However, the mean percentage of accurately reporting the target location was less with the prism. At times this difference reached 20%, yet was not statistically significant. The differences were found because the perceived location of the target seen through the prism is not the true location. Further, finding a difference could be because the participants judged the location of the targets in relation to the central cross or the edge of the screen which may have led them to inaccurately report the target location. This inaccuracy could be compensated for after using the prism for a period of time as found in previous research (Kohler, 1964, Pick et al., 1969, Welch et al., 1993). For example, Kohler (1964) reported adaption to the change after ten days of full-time wearing a binocular half-prism. Our expectation was that the participants wearing the prism would adapt to the change in location after a period of time. Yet, the mean accuracy of the target location in Visit 3 was almost the same as reported in Visit 2. This is could be accounted for by the fact that the prism was worn
only for a short and intermittent period of time. The participants' wearing times ranged from to one to two hours a day.

Generally, neither prism over the short period of time seems to have improved the DT scores; except for the results obtained from TVP 4’s performance. The participants in TVPs 20° and TVPs 10° scored DTs which were the same or longer than the DTs without the prisms. Interestingly, in the TVPs 5° group, a marked improvement in DT manifested in a few participants (TVPs 16, 18 and 19). The improvement in DT was sometimes up to 50%, e.g. for TVP 18. The mobility scores with the prisms in the three groups varied: slightly improving, remaining stable or deteriorating. In general, the results obtained from the AVA test indicate that both prisms hindered the participants and did not provide additional information that would help them to practise their everyday activities efficiently and smoothly in the long term follow-up. In the third visit, the results collected from the AVA test and the mobility scores were not markedly different from the second visit's scores. This result indicates the sensitivity of the AVA test which was able to predict the participants’ performance on the mobility course. In TVPs 5° group, finding improvement in the DT scores with the prism on the second visit and not finding improvement in mobility performance after extended wear seems to be due to their being generally slow walkers who were trying to become aware of their surroundings before taking a decision. Whatever aid is proposed to this group would not improve their score to match those, for example, in the TVP 20° group and might indeed hinder them as it would interfere with their compensatory strategies. This overall outcome could indicate that using the optical aid in this group (4° to 6° FoV) is highly questionable.

The formal and informal feedback was collected after trying the prisms for a longer period of time. In the formal feedback, the changes in the scores between with and without the prism
were not dramatic (i.e. generally one step on the scale towards more difficulty or problems), yet there was a clear suggestion that the participants were facing more challenges. The informal feedback was also supportive of the conclusion that the prisms were not functionally useful. These results could indicate that the prisms did not provide the participants with the additional information needed to show a noticeable enhancement of their performance even after a period of adaptation. Not only that, but most of the time the prism actually hindered them which may indicate that the prism interfered with their adopted compensatory strategies. This result was a surprise as we had not considered the possibility that the majority of the participants would not benefit from the prisms. This result could suggest the importance of the AVA test as a reliable method of exploring the efficacy of optical aids for TV patients.

Success with the prism, as defined by an obvious and marked improvement in the DT scores, was only experienced by TVP 4, whose DT scores with the partial aperture prism were improved by about 50%. The PPWS increased by about 20%, but an increase in collisions was also observed (increase by 0.50 collision). The increase in collisions may indicate that there was difficulty in adapting to the prism. The participant used the prism over a longer period of time (four weeks) and further improvement in mobility scores were recorded, where the PPWS had increased and no collision was recorded. This could mean that after wearing the prism for an extended period the participant had developed a strategy for successfully using it. Further, it was interesting to find that the DT scores recorded on the third visit were similar to those recorded on the second visit. In the participant's formal feedback, she expressed positivity, and even though the changes in scores were minimal, they were in the direction of having less difficulty with the prism. The participant's informal feedback also provided support of the efficacy of the partial prism where she reported that she felt more aware of obstacles to the sides and the steps and curbs. Her only reasons for not using the
prism were the cosmetic appearance and that she was used to the long cane. There are no obvious reasons why this participant benefited from the prism while some of the others in the same group with the same level of visual functions measures (e.g. TVP 3) did not. However, the AVA test provided a clear indication that the partial aperture prism for this particular individual was promising. Although this does not mean that the second visit was sufficient and no further follow up visit(s) are required. In the follow up visit(s) further assessment using the AVA test and the participant's feedback could be collected. Any changes or adjustments to the optical aid would be performed in these visits.

No obvious link was found between the participants' visual function or using (or not using) the cane and the success of the prism. However, what was noticed in TVP 7 is the effect of modest to severe CS limitation on the DT scores with the prism, where the DT was doubled or sometimes tripled. In contrast, his PPWS and collisions did not change with the prism as he was already walking slower than his matched participant with equivalent FoV and VA (e.g. TVPs 6 and 5). He walked really slowly (PPWS = 37%), in comparison to other participants in the same group, possibly trying to be alert to the obstacles in his path.

Even though the Tri-field prism and the partial aperture prism were not found to help the majority of the TVPs and were rejected, the participants’ reactions towards them were different. The response towards the partial prism was generally less negative than that towards the Tri-field prism. The partial aperture prism was rejected as there was no tangible performance enhancement, difficulty in walking outside, poor image quality and for cosmetic reasons. On the other hand, the Tri-field prism was found to be a good concept, although it caused confusion, disorientation in crowds, headaches, eyestrain, dizziness, discomfort and occasionally diplopia. The partial prism appeared to cause less difficulty than the Tri-field prism. Further, although the Tri-field prism expands the VF laterally, the inferior part of the
VF is not expanded (Woods et al., 2010a). The inferior VF is known to be highly important for mobility (Lovie-Kitchin et al., 1990). The Tri-field power was relatively high and was fitted in front of one eye, thus to some extent causing spatial distortions. These additional drawbacks might be why the participants seemed to prefer the partial aperture prism over the Tri-field prism.

Generally, the results collected from the participants indicate that both prisms hindered the participants except in one case. We are aware of three studies that used the same sort of prisms in patients with TV. The partial aperture prism was used in Hoppe and Perlin (1993) and Somani et al. (2006). Hoppe and Perlin (1993) reported that 18 patients out of 22 continued wearing the prism (the study is discussed in detail in Chapter 2, section 2.2). The wearing time varied from 2 to 26 months, however, most of the patients continued to use the long cane in addition to the Fresnel prism. They reported that the satisfaction level for the mobility category was good, ranging from 3 (somewhat satisfied) to 4 (very satisfied). Somani et al. evaluated the efficacy of spectacle-mounted prisms using a vision-related ADL questionnaire and functional visual field score (FFS) measurements. The second measurement is derived from the VF size (described in Chapter 2, section 2.2.1). They reported a statistically significant improvement in the peripheral tasks part of the V-ADL (14% improvement in the scores between with and without the prism). They also suggested that there was a significant improvement in the FFS scores by 9% (i.e. a change from 23 to 27 points). The results in these two studies differ from those we obtained in the present study. This is could be because of the measures that were used in these studies, and the questionnaires are subjective, which means that they are more prone to bias than the objective approaches. Besides that, Hoppe and Perlin did not collect baseline responses on the same survey before using the prisms in order to compare their scores before and after use. Further, the patients reported that they were using the long cane while moving about which could
mean that they were not able to depend on the prism alone. Further, the improvement in V-ADL scores were marginal and could be as a result of variability. The improvement in the FFS would not be strong evidence of the efficacy of the prism as it is derived from the VF, and it is well known that the partial aperture prism does not expand the VF but relocates peripheral objects when an eye movement takes place. Therefore, the changes in the FFS scores appears to be due to variability as they were not very different from each other (i.e. 23 to 27 points).

Woods et al. (2010a) tested the efficacy of the Tri-field for extended wearing. Their main measure of efficacy or clinical success was the number of participant who chose to continue wear the Tri-field prism at the end of the study (Visit 5 in this case). They also used two questionnaires, which were administered at the first visit and at the end of the study (Visit 5). The questionnaires comprised the items from NEI-VFQ 25 (Mangione et al., 2001) and from the IMQ (Turano et al., 1999a) which related to mobility. Woods et al. reported that nine out of the thirteen participants continued to wear the prism at Visit 5, however, only three reported that they were still wearing the Tri-field prism after a long-term telephone follow-up (median 48, range 35–78 weeks). They found that the participants perceived an increase in difficulty in visiting people in their homes, at parties, or in restaurants. Further, the successful participants were more likely to report that they "stay at home most of the time because of my eyesight ". In the items from the IMQ, at the start of the study, successful participants reported greater difficulty in moving about at work, avoiding bumping into walls and avoiding shoulder height objects, than non-successful participants. However, Woods and co-workers did not provide the raw data of the participants’ questionnaire responses. This could be due to the limited space available in their paper, and means that we are not able to compare our findings with theirs. They also reported that at the end of study (Visit 5), none of the participants demonstrated adaptation to the prismatic image displacement even though
they used the multiplexing concept and had tinted the Tri-field segments with different colours. They account for this as being due to the lack of adaption possible during the short wearing time (median 1.20 hours, ranging from 0.6 to 3.8 hours each day, for successful participants). The participants reported difficulties with the Tri-field including diplopia, difficulties in steps and stairs, dizziness, and difficulties in low-light situations. Crowded situations were particularly difficult for majority of the participants.

The results found by Woods et al. (2010a) are, generally, not so very different from our own and we have reported similar difficulties here. The questionnaire response could not be compared as no raw data was provided. Further, we do not know exactly when the participants who chose to continue wearing the prism after the end of the study stopped using it, even though we know when they were called for a follow-up. This means that the participants could have stopped wearing the device at any point from the end of the study to the long-term follow-up phone call. On the other hand, we had, in this study, a lower success rate than that found in Woods et al. This difference in success rate could be accounted for by many reasons, for example the training provided to the participants was limited because the visit was relatively long (taking about three hours as the two visits were combined) and we did not want to push the participants’ physical and psychological limits. Also, the number of visits was less than in Woods et al. and this is because the participants lived outside the city and more visits were not feasible. The lower number of visits may have led to less wearing time. The prism used in this study was the Fresnel prism, which is known to produce a poorer quality of image in comparison with the Tri-field prism in the Woods study, in which a pair of glasses was customised for each participant.
In general, the success rate in our study was low, as only one participant showed marked improvement, as documented by the AVA test, mobility course and the formal and informal feedback. However, this result could provide an indication of the sensitivity and significance of the AVA test in assessing optical aids for the improvement of mobility in TV patients. Aside from the fact that the prisms work by shifting the image, the reasons for our low success rate may be because patients with TV at the levels featured in our study (20° or less) have lived with this condition for many years while slowly losing their peripheral field. This means that they have developed compensatory strategies that the prisms interfere with. Further, due to the slow progression of the disease they may have changed their lifestyle to avoid the challenges of moving about by limiting their travel. These participants also suffer from night blindness, which means that they would not use the prism in dim places or during the night. This may be have led to them using the prism much less, which prevented them from gaining the necessary experience.

In summary, finding that the prism is not a very useful aid was a surprise, as for many years it has been promoted as an effective rehabilitation intervention to enhance the mobility performance of TVPs. The AVA test results show that these aids did not generally bring about any improvement, except for one participant, indicating that the test is a reliable measure. The sensitivity of the AVA test could be further explored using a different rehabilitation approach. The prisms were chosen in this instance because there is a limited number of potentially effective optical aids for TVPs. The prisms used here were the realistic choice at the start of our study as the other potential optical aid, the reverse telescope, was not commercially available. Therefore, the use of a monocular partial aperture prism has been suggested, in order to explore the efficacy of this design. This aid enables the participant to retain normal view with one eye while the image in the other eye is shifted. However, towards the end of our study a new brand of reverse telescope was introduced into the
market. We have seen the potential advantages of using this device as the telescope expands the VF, thus enabling the peripheral targets (or obstacles) to be perceived instantly. The role of the AVA test in assessing the impact of the reverse telescope on the participants’ performance is discussed next in Chapter 12.
Chapter Twelve: The Role of the AVA Test in Predicting the Impact of the Reverse Telescope on TVP and SIP Performance
12.1 Study Rationale, Aims and Hypothesis

The Fresnel prisms were found to have limited success in enhancing TVP performance (Chapter 11). This was found in both the selected objective methods and in the formal and informal feedback. An alternative optical aid that would potentially benefit these patients is the reverse telescope (RTS). In 2012, a UK supplier introduced a RTS into the market, making it possible to investigate the effectiveness of this optical aid in improving AVA and mobility performance in patients with real defects (TVPs) and healthy volunteers with simulated impairment (SIPs). The RTS expands the VF by condensing details from a larger field into the available FoV of the wearer. This means that objects to the sides can be perceived instantly, providing the wearer with the information necessary for awareness of these objects and enabling safer and more efficient navigation.

The enhancement of performance with the RTS in TVPs is expected to vary between participants. This is because, as discussed earlier in Chapter 11, the TVPs differ in their visual and non-visual characteristics. Briefly, the RTS is expected to positively impact the AVA scores, but this improvement may not be apparent in all patients due to interference with their existing compensatory strategies. The participants’ scores in the mobility course are expected to be worse with the RTS in the short term. This is because one of the major limitations of the RTS is that objects look further away than they really are. This may lead to confusion, but after a longer period of time the participants are expected to adapt to the change in object location. On the other hand, after using the RTS for a longer period of time, further improvement in DT scores is expected or at least that the participants maintain their baseline DT scores with the RTS. Mobility performance is expected to improve as a result of adaptation. These improvements are expected to be supported by the TVPs’ formal and informal feedback.
The SIP performance scores with the RTS are expected to be similar within this group, in comparison to the TVP performance scores. This is because the SIPs are a homogenous group with similar visual and non-visual characteristics (i.e. no long-term adaption experience; similar age, VA and CS). The vast majority of the SIPs are expected to show a marked improvement in DT in conjunction with RTS. The mobility scores are expected to be worse with the RTS due to the change in obstacle location. However, as the participants will complete the mobility course four times with the different simulators, a marginal improvement in mobility scores is expected as the FoV becomes more constricted. This is because the SIPs will be more familiar with the change in obstacle location.

12.2 Materials and Methods

The TV participants and SIPs that were previously recruited to be involved in the studies were contacted to participate in this study. Invitations were also sent to patients with TV via the Facebook groups mentioned in Chapter 5, section 5.3.2 in order to recruit new participants, however, no new patients came forward. Four TVPs and twelve SIPs who had previously participated in the main study were involved in this research and visited our lab to help us investigate the efficacy of the RTS.

The design, advantages and limitations of the RTS have been described earlier (Chapter 2, section 2.3). Briefly, the RTS expands the VF and thus provides more information about the surrounding areas, but with a trade-off in image size (Dickinson, 1998). The expansion of VF and the decline in VA can be estimated from the telescope power. For instance, if the RTS power is 0.50X, as in our study, the expected expansion would be an increase by a factor of two. The VA is expected to proportionally decline in accordance to the RTS power. Based on this, the RTS 0.50X in our study is estimated to cause a decline in VA from, for example, 0.00 logMAR to 0.30 logMAR. The RTS has other limitations, which include the limitation
of eye movements, difficulty in adjusting to moving objects, difficulty in judging distances, the restricted range of parameters available commercially, and the disadvantage that the actual field does not match the predicted one because of the limited FoV of the device (Bailey, 1978a, Mehr and Quillman, 1979, Frith, 1979, Holm, 1970, Drasdo, 1976, Weiss, 1992, Dickinson, 1998).

The RTS used in this study is from Multilens Optical Solutions in Mölnlycke, Sweden. It has a magnification of 0.5X and is the trial-ring version for mounting in a trial frame for the experiments (Figure 12.1). In this study, the RTS was used monocularly due to difficulty in aligning the binocular device. The RTS was fitted in front of the eye with best VA (if there was a difference), while the other eye was covered to try to eliminate any confusion caused by the use of both eyes. As the RTS is not adjustable to compensate for refractive errors, the refractive errors of both the TVPs and SIPs were incorporated in the trial frame. In the SIPs, the TV simulators were also incorporated in the trial frame with the RTS, and the side shields were also used. The expanded field was checked by repeating the VF test while the RTS was worn. To familiarize the participants with the use of the RTS they were escorted outside the lab for a short walk through a quiet corridor. As described in the previous chapter, the participants were asked to pay attention to doorframes, chairs and the location of walls. Then they were asked to wear the RTS for 30 minutes before doing the objective tests.
In Figure 12.1, Upper left: the normal view of the logMAR VA ETDRS chart at 1m. Upper right: view of the VA chart through the 20° simulator. Bottom left: the RTS in the trial-ring. Bottom right: view of the VA chart while wearing the simulator and the RTS, showing the effect of the expanded VF, which changes the image size and object location.

The AVA test, the mobility course and the TV simulators as described previously were used in this study. The TVP and SIP baseline scores (i.e. without the aid) were their scores on the first visit (mean separation between visits was five weeks for TVPs and twelve weeks for SIPs). The SIPs did the proposed tests with the first three simulators (20°, 15° and 10°) in decreasing order. The 5° simulator was not included as the simulator is a thick device that would not allow space for the RTS in the same trial frame.

It was intended to investigate the effectiveness of the RTS over an extended period of wear. However, none of the TVPs were willing to volunteer for this. Therefore it was decided to
monitor the SIPs in using the RTS over five further visits on consecutive days. However, only one of the participants agreed to do the experiment; the others did not have time to visit every day. In each visit the SIP walked down the corridor outside the lab for a few minutes before doing the mobility course. The approach of adopting five consecutive days was chosen as this was the closest to the experience that a real TVP would go through, i.e. wearing the RTS on a daily basis. In this part of the study the layout of the mobility course was changed on each alternate visit (i.e. on the first, third and fifth visits). However, the same concept of the mobility course was used, in which the participants were asked to take repeated decisions while navigating the course and the same number and type of obstacles were used. The course layout was changed for two reasons: firstly the mobility course results were found to be influenced by the learning effect in the long-term (discussed in Chapter 10, section 10.3.2) and secondly we wanted to challenge the participant by avoiding previous route planning, in order to find out if the RTS provides a tangible benefit over a reasonably long period of time.

The participants' visual functions were measured with the same tests used in Chapter 11, section 11.2.

### 12.3 Participant Characteristics

The mean age of the four TVPs (three females and one male) who participated in this study was 47 years (ranging from 40 to 55 years). The TVPs VA mean, with the RTS, was 0.32 logMAR (ranging from 0.20 to 0.44 logMAR). The mean age of the SIPs was 22 years (ranging from 19 to 27 years). The mean VA of the SIPs, with the RTS, was 0.10 logMAR (ranging from 0.00 to 0.26 logMAR). The expanded VF with the RTS matched expectations; where the VF size (in degrees) was approximately doubled in both the TVPs and SIPs.
12.4 Results

12.4.1 Location Accuracy

The mean percentages accuracy of correctly detecting the target location and direction for both TVPs and SIPs groups is summarized in Table 12.1. The accuracy of the target direction was high and did not vary between groups or eccentricities (Table 12.1). The accuracy of the target location did change before and after using the RTS, especially at the 3rd and 4th annulus. However, the Chi-square test for independence showed that the RTS did not significantly impact both position measures ($p > 0.05$) regardless of the FoV size.

Table 12.1 The accuracy of reporting the target position and direction in the TVPs and the SIPs groups

<table>
<thead>
<tr>
<th>Position</th>
<th>TVPs</th>
<th>SIPS 20</th>
<th>SIPS 15°</th>
<th>SIPS 10°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without/ with RTS</td>
<td>Without/ with RTS</td>
<td>Without/ with RTS</td>
<td>Without/ with RTS</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>99% / 97%</td>
<td>99% / 98%</td>
<td>100% / 98%</td>
<td>100% / 97%</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>98% / 93%</td>
<td>99% / 93%</td>
<td>99% / 93%</td>
<td>99% / 92%</td>
</tr>
<tr>
<td>4th annulus</td>
<td>99% / 91%</td>
<td>99% / 92%</td>
<td>99% / 94%</td>
<td>99% / 90%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Direction</th>
<th>TVPs</th>
<th>SIPS 20</th>
<th>SIPS 15°</th>
<th>SIPS 10°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without/ with RTS</td>
<td>Without/ with RTS</td>
<td>Without/ with RTS</td>
<td>Without/ with RTS</td>
</tr>
<tr>
<td>2nd annulus</td>
<td>99% / 97%</td>
<td>100% / 100%</td>
<td>99% / 99%</td>
<td>100% / 99%</td>
</tr>
<tr>
<td>3rd annulus</td>
<td>99% / 99%</td>
<td>99% / 98%</td>
<td>100% / 99%</td>
<td>98% / 99%</td>
</tr>
<tr>
<td>4th annulus</td>
<td>100% / 99%</td>
<td>100% / 99%</td>
<td>99% / 99%</td>
<td>99% / 98%</td>
</tr>
</tbody>
</table>

12.4.2 The Impact of RTS on the TVPs Performance

The approach used to analyse the TVPs’ performance with the RTS was the same as in the prism study (Chapter 11, section 11.4), with participants’ performances investigated individually. The TVP reference IDs are the same as those used in Chapter 11, to enable us to compare the participants’ responses toward both aids (i.e. prisms and RTS).

Two participants with the RTS (TVP 4 and TVP 15) showed a noticeable improvement in DT scores at the three annuli (Table 12.2). However, their PPWS reduced by about 15% and double the collision incidences took place. TVP 14 showed a minimal change in DT scores at
the three annuli and the PPWS was approximately halved, while there were about eight times as many collisions (Table 12.2). TVP 17 was slower at the 2nd and 3rd annulus with the RTS, yet faster DT was found at the 4th annulus. The mobility performance of this TVP was not very different from their performance without the RTS.

Table 12.2 TVP background data and scores in the AVA and mobility tests, before and after using the RTS

<table>
<thead>
<tr>
<th>ID reference</th>
<th>VF</th>
<th>VA</th>
<th>CS</th>
<th>Long cane/ O and M training</th>
<th>DT 2nd annulus</th>
<th>DT 3rd annulus</th>
<th>DT 4th annulus</th>
<th>PPWS</th>
<th>Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVP 4 Visit 1</td>
<td>21°</td>
<td>0.10</td>
<td>1.75</td>
<td>yes/no</td>
<td>2.03</td>
<td>3.31</td>
<td>5.31</td>
<td>49.00</td>
<td>0.50</td>
</tr>
<tr>
<td>TVP 4 Visit 2</td>
<td>1.29</td>
<td>1.54</td>
<td>2.60</td>
<td>35.00</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TVP 14 Visit 1</td>
<td>12°</td>
<td>0.20</td>
<td>1.60</td>
<td>no/no</td>
<td>1.19</td>
<td>2.38</td>
<td>5.80</td>
<td>83.50</td>
<td>1</td>
</tr>
<tr>
<td>TVP 14 Visit 2</td>
<td>0.95</td>
<td>2.33</td>
<td>5.00</td>
<td>46.75</td>
<td>8.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TVP 15 Visit 1</td>
<td>9°</td>
<td>0.00</td>
<td>1.70</td>
<td>no/no</td>
<td>2.95</td>
<td>6.72</td>
<td>5.89</td>
<td>32.50</td>
<td>0.50</td>
</tr>
<tr>
<td>TVP 15 Visit 2</td>
<td>1.42</td>
<td>3.22</td>
<td>3.41</td>
<td>27.00</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TVP 17 Visit 1</td>
<td>4°</td>
<td>0.16</td>
<td>1.50</td>
<td>yes/yes</td>
<td>3.63</td>
<td>18.95</td>
<td>46.62</td>
<td>23</td>
<td>1.50</td>
</tr>
<tr>
<td>TVP 17 Visit 2</td>
<td>4.33</td>
<td>22.45</td>
<td>8.54</td>
<td>22</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12.4.3 The Impact of RTS on the SIPS Performance

The SIPS performance with the RTS was investigated as a group. This is because their performances were similar to each other. Statistical tests were used to analyze their performance: their scores were explored for normality and the Kolmogorov-Smirnov test showed that the scores were not normally distributed (p < 0.05), therefore non-parametric tests were used. The Wilcoxon signed-rank test was used to compare the participants’ performances before and after the use of RTS.

Generally, the SIPS performance in the AVA test with the three simulators significantly improved with the RTS (Table 12.3, Figure 12.2). However, PPWS was significantly slower and there were significantly more collisions with the RTS (Table 12.3, Figure 12.3,12.4).
Interestingly it was noticed that the PPWS with the RTS gradually improved as the FoV became more constricted (Table 12.3). The same pattern was found in the collision scores, with collisions gradually decreasing as the FoV diminished and the difference in scores with and without the RTS narrowed until there was no significant difference between the collision scores in SIPs 10° (Table 12.3). In contrast, the DT scores with the RTS did not become shorter as the FoV constricted, but were proportionate to the DT without the RTS.
Table 12.3 The median ± IQR of DT scores and mobility scores in the three FoV sizes, with Wilcoxon test results comparing scores before and after using RTS

<table>
<thead>
<tr>
<th></th>
<th>DT 2\textsuperscript{nd} annulus</th>
<th>DT 3\textsuperscript{rd} annulus</th>
<th>DT 4\textsuperscript{th} annulus</th>
<th>PPWS</th>
<th>Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIPs 20° without aid</td>
<td>1.524 ± 1.18</td>
<td>3.572 ± 1.243</td>
<td>4.564 ± 1.33</td>
<td>54.00 ± 25.50</td>
<td>0.50 ± 1.00</td>
</tr>
<tr>
<td>SIPs 20° with aid</td>
<td>1.09 ± 0.722</td>
<td>1.304 ± 0.636</td>
<td>2.369 ± 1.490</td>
<td>34.75 ± 27.00</td>
<td>2.50 ± 2.25</td>
</tr>
<tr>
<td>Wilcoxon test</td>
<td>$Z = -2.20, p = 0.028^*$</td>
<td>$Z = -3.06, p = 0.002^*$</td>
<td>$Z = -2.82, p = 0.005^*$</td>
<td>$Z = -3.10, p = 0.002^*$</td>
<td>$Z = -2.55, p = 0.01^*$</td>
</tr>
<tr>
<td>SIPs 15° without aid</td>
<td>1.965 ± 0.942</td>
<td>5.019 ± 1.459</td>
<td>6.458 ± 1.745</td>
<td>52.25 ± 26.00</td>
<td>1.25 ± 1.75</td>
</tr>
<tr>
<td>SIPs 15° with aid</td>
<td>1.103 ± 0.629</td>
<td>1.690 ± 0.823</td>
<td>3.362 ± 1.667</td>
<td>42.75 ± 16.25</td>
<td>1.75 ± 2.00</td>
</tr>
<tr>
<td>Wilcoxon test</td>
<td>$Z = -3.06, p = 0.002^*$</td>
<td>$Z = -3.06, p = 0.002^*$</td>
<td>$Z = -2.66, p = 0.008^*$</td>
<td>$Z = -3.10, p = 0.002^*$</td>
<td>$Z = -2.53, p = 0.01^*$</td>
</tr>
<tr>
<td>SIPs 10° without aid</td>
<td>2.334 ± 1.524</td>
<td>5.116 ± 1.99</td>
<td>6.658 ± 3.046</td>
<td>48.75 ± 30.00</td>
<td>1.50 ± 1.50</td>
</tr>
<tr>
<td>SIPs 10° with aid</td>
<td>1.00 ± 0.587</td>
<td>1.927 ± 0.761</td>
<td>4.259 ± 1.935</td>
<td>42.25 ± 21.50</td>
<td>1.00 ± 2.50</td>
</tr>
<tr>
<td>Wilcoxon test</td>
<td>$Z = -2.98, p = 0.003^*$</td>
<td>$Z = -3.06, p = 0.002^*$</td>
<td>$Z = -3.06, p = 0.002^*$</td>
<td>$Z = -2.04, p = 0.04^*$</td>
<td>$Z = -0.24, p = 0.81$</td>
</tr>
</tbody>
</table>

* indicate statistically significant, $p < 0.05$
Figure 12.2 The DT scores at the 3rd and 4th annulus in the three FoV sizes. The DT scores can be seen to decrease significantly when the RTS is used.

Figure 12.3 The PPWS scores in the three FoV sizes with and without the RTS.
Figure 12.4 The collision scores in the three FoV sizes before and after using the RTS.
12.5 The Impact of Extended Wear on SIP Performance

SIP 10 agreed to use the RTS while wearing the three simulators for five visits after the first visit. It was noticed that the participant's DT scores showed a marked improvement with the RTS when also using each of the three simulators on the initial visit (Table 12.4). These AVA test results indicated that this participant was likely to be successful in using the RTS. On the initial visit the PPWS declined by 10 to 15% and more collisions took place. However, in the following visits the PPWS gradually increased and there were fewer collisions (Table 12.4), indicating that the participant was becoming more used to the device.

In detail, the DT scores with FoV of 20° at the 3rd and 4th annulus showed minimal variation between visits, yet at the end of the trial the DT scores were nearly equal to the DT on the first visit (with the RTS) (Table 12.4). Further, the DT scores at the 3rd and 4th annulus within each FoV of 15° and 10° varied between visits, however, shorter DTs were now being recorded. Surprisingly, the DT scores at the 3rd and 4th annulus for the FoV of 15° and 10° were approximately equal to the DT scores for the same participant with the 20° simulator (Table 12.4). Interestingly, the participant's PPWS and collisions were almost equal to the scores with the three simulators at the end of the trial (Visit 6). This means that there was a marked enhancement which enabled the participant to perform better and match his scores with those expected of a bigger FoV. Further, within each FoV, the PPWS scores at the end of the trial were equal to or better than the PPWS scores without the RTS (Table 12.4). These results could indicate that use of the RTS leads to noticeable performance enhancement. For example, SIP 10’s PPWS with a FoV of 10° was 60% with no collisions; whereas the same participant’s PPWS at the baseline,
with the FoV of 20°, had been 57% with 1.50 collisions (Table 12.4).

Table 12.4 SIP 10 DT scores and mobility scores with the three simulators at each visit

<table>
<thead>
<tr>
<th>DT 2nd annulus</th>
<th>DT 3rd annulus</th>
<th>DT 4th annulus</th>
<th>PPWS</th>
<th>Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SIP 10 with 20° FoV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline (Without RTS)</td>
<td>1.452</td>
<td>2.267</td>
<td>3.661</td>
<td>57.00</td>
</tr>
<tr>
<td>Visit 1</td>
<td>1.161</td>
<td>1.361</td>
<td>1.972</td>
<td>34.75</td>
</tr>
<tr>
<td>Visit 2</td>
<td>1.435</td>
<td>1.547</td>
<td>2.105</td>
<td>40.75</td>
</tr>
<tr>
<td>Visit 3</td>
<td>0.979</td>
<td>1.199</td>
<td>1.951</td>
<td>49.25</td>
</tr>
<tr>
<td>Visit 4</td>
<td>0.664</td>
<td>0.765</td>
<td>2.030</td>
<td>53.00</td>
</tr>
<tr>
<td>Visit 5</td>
<td>0.828</td>
<td>1.359</td>
<td>1.920</td>
<td>53.75</td>
</tr>
<tr>
<td>Visit 6</td>
<td>1.043</td>
<td>1.176</td>
<td>1.718</td>
<td>59.25</td>
</tr>
<tr>
<td><strong>SIP 10 with 15° FoV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline (Without RTS)</td>
<td>1.581</td>
<td>3.905</td>
<td>6.482</td>
<td>50.00</td>
</tr>
<tr>
<td>Visit 1</td>
<td>1.251</td>
<td>1.000</td>
<td>3.383</td>
<td>40.75</td>
</tr>
<tr>
<td>Visit 2</td>
<td>1.288</td>
<td>1.515</td>
<td>2.126</td>
<td>43.75</td>
</tr>
<tr>
<td>Visit 3</td>
<td>0.788</td>
<td>0.951</td>
<td>2.102</td>
<td>49.25</td>
</tr>
<tr>
<td>Visit 4</td>
<td>0.686</td>
<td>0.897</td>
<td>1.824</td>
<td>53.75</td>
</tr>
<tr>
<td>Visit 5</td>
<td>0.893</td>
<td>1.072</td>
<td>2.369</td>
<td>51.25</td>
</tr>
<tr>
<td>Visit 6</td>
<td>0.831</td>
<td>1.055</td>
<td>1.955</td>
<td>59.50</td>
</tr>
<tr>
<td><strong>SIP 10 with 10° FoV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline (Without RTS)</td>
<td>1.664</td>
<td>5.543</td>
<td>6.582</td>
<td>45.00</td>
</tr>
<tr>
<td>Visit 1</td>
<td>1.006</td>
<td>1.900</td>
<td>3.499</td>
<td>39.50</td>
</tr>
<tr>
<td>Visit 2</td>
<td>0.857</td>
<td>1.166</td>
<td>2.141</td>
<td>44.25</td>
</tr>
<tr>
<td>Visit 3</td>
<td>0.852</td>
<td>0.985</td>
<td>2.959</td>
<td>45.25</td>
</tr>
<tr>
<td>Visit 4</td>
<td>0.758</td>
<td>1.161</td>
<td>3.311</td>
<td>60.00</td>
</tr>
<tr>
<td>Visit 5</td>
<td>0.739</td>
<td>1.296</td>
<td>3.175</td>
<td>53.75</td>
</tr>
<tr>
<td>Visit 6</td>
<td>0.995</td>
<td>1.190</td>
<td>2.085</td>
<td>60.00</td>
</tr>
</tbody>
</table>
12.6 General Discussion

In this study the role of the AVA test in predicting the efficacy of the RTS was investigated. The RTS expands the VF, but this is at the expense of a reduction in the image size and the perceived location of objects is also affected. The number of TVPs recruited in this study was small, and this was a limitation of the study. These participants also rejected the idea of using the RTS for an extended period because they were unable to travel to Manchester again. To attempt to investigate the sensitivity of the AVA test in predicting the effect of the RTS in a larger group, the SIPs were re-recruited. However, in the extended wear trial, only one participant agreed to take part, and this was a second limitation of the study. However, even with these limitations, some useful patterns emerged.

Firstly, the ability to identify the target direction did not change after using the RTS. This result was expected as the RTS minimises the image but does not manipulate the object location. Further, accuracy of detecting target location was greater without the RTS. However, these differences were not statistically significant and were found because the target locations seen through the RTS were perceived in the non-natural locations. This may mean that the participants were judging the location of the targets in relation to the central cross or the edge of the screen which may have led them to inaccurately report the target location. These differences were not significant and are expected to be compensated for after using the RTS for a period of time in the same way that was found with the prism (Kohler, 1964, Pick et al., 1969, Welch et al., 1993). We expected that participants wearing the RTS would adapt to the change in location after a period of time and that this would show in lower collisions scores. However, this issue was not
investigated in depth as the wearing time in this study was short and intermittent (i.e. only while conducting the tests).

The AVA test provided clear indication of the efficacy of the RTS for all of the TV participants. In detail, two participants (TVP 4 and TVP 15) showed a marked improvement in the DT scores, but their performance in the mobility course was worse than their scores without the RTS. The improvement in DT could be considered as an indication that the RTS provides some useful information about the peripheral targets which enables participants to respond faster than without the RTS. Further, the negative impact of the RTS on the participants' performance in the mobility course was expected. This is due to the RTS causing perceived changes in object size location. TVP 14 and TVP 17 were not found to record better scores either in the AVA test or on the mobility course. Specifically, TVP 14 did not benefit from the use of the RTS, and this is could be due to the fact that her baseline scores in the mobility course indicated that she is a good performer (PPWS = 80% and 1 collision). This could mean that she already has efficient compensatory strategies which lead to a good dynamic field and that the RTS was interfering with these strategies. TVP 17 had a FoV of 4° and as seen in the previous study (Chapter 11, section 11.4), this group of participants' scores are highly variable, which may lead to misinterpretation of their performance. Further, this participant always walked very slowly (about 20%) and as this did not change with the RTS, it might indicate that he had adopted this as a strategy which the RTS was not able to change. Even with this adopted strategy, however, TVP 17 seemed to be at risk of colliding with the side obstacles, as he scored about two collisions with and without the RTS. Finally, what was also interesting is that TVP 4, who benefited from the partial aperture prism
and recorded a better performance with it, also found the RTS useful, and this seems to be because she was motivated and ready to incorporate the device into her compensatory strategies.

The SIPs reactions were similar towards the use of the RTS, and DTs with the RTS were shorter. This result could indicate that the RTS provided more information about the peripheral targets. The participants' mobility scores were worse in comparison to their scores without the RTS. This is accounted for by the reasons mentioned earlier regarding the TVP group.

In detail, the SIPs’ mobility scores improved as the FoV contracted. These scores with the RTS contradict their scores without it. Further, the differences in mobility scores between with and without RTS decreased as the FoV contracted. This is may be due to the SIPs becoming experienced with the RTS in a relatively short period of time. This also means that they were adapting to the changes in image size and obstacle location. These findings suggest that the AVA test can predict the efficacy of the RTS.

The efficacy of the RTS over an extended period of wear was explored in one SIP. It had been planned to explore the RTS efficacy in real TVPs for a longer period of time, but since none of the TVPs agreed to take part in this study, five further visits were planned for one of the SIPs to try the RTS. In each visit the SIP walked up and down the corridor outside the lab for few minutes before doing the mobility course. The SIPs group showed that they gain experience in a short period of time; they scored better mobility scores as the FoV diminished. Therefore, it was expected that over time the SIP would improve familiarity with the aid and that this would lead to a gradual improvement in scores.
The participant who volunteered for the study showed some indication of adaptation. In detail, the mobility scores changed over the visits in the direction of gradually improved performance. At the end of the study the participant's mobility scores were equal to those with the three simulators. This improvement in mobility scores could not be explained by the learning effect because we changed the layout of the obstacles three times while maintaining the same complexity level, in order to avoid any pre-planning of the route. The improvement in the mobility performance may provide indication of the effectiveness of the RTS. What was also interesting was that the DT at the 3rd and 4th annulus in the FoV of 20° varied between visits but remained within the same range; this is most probably due to the floor effect. The DT scores at the 3rd and 4th annulus, in the FoV of 15° and 10° varied between visits but scores better than those on the initial visit were recorded. At the end of the trial the DT scores, at both annuli, were equal to the DT scores at the corresponding annuli in FoV of 20°. This result contradicted our expectation of the effect of optical aids and/or training on the AVA test scores over a long period of time. It had been thought that the DT scores would not record any further improvement over the long-term and that mobility performance would improve with time. This result also suggests that improvement in mobility scores is associated with improvement in DT if an efficient intervention is introduced. Further, this result may also suggest that adaptation to the RTS does not take a long time and could be even shorter in patients with real defects as they are already experienced in dealing with the condition. Finally, this result could indicate that improvements in AVA scores caused by an intervention can potentially lead to better performance in the mobility test and any improvement in mobility performance might also show up in better AVA test results, although we do not
have evidence to support this hypothesis. However, we have to acknowledge that this expectation could only be tested satisfactorily if other variables are controlled. This is because there are several factors which influence mobility performance including: health status, age, adaptation, training, sudden elimination cues, visual functions, confidence and motivation.

In general, even though the small number of participants was a limitation, the participants themselves were not chosen by us, which eliminates the possibility of pre-prepared outcomes by recruiting only good performers. These participants came forward voluntarily which may indicate that they have the motivation to adopt the new aid. These results could also signify the importance of the AVA test as a measure of the efficacy of optical aids in TV participants. Overall, the RTS seems to be a more efficient optical aid in comparison to the partial aperture prism and the Tri-field prism. Yet, the RTS has a few drawbacks which may need adaptation, such as adjusting to moving objects, diminished image size and perceived change in object location. Therefore, the needs of each individual should be considered, as some patients may benefit from continuous wear (as a full diameter FE or bioptic design), while others may benefit from a clip-on or handheld aid for occasional use.

In the literature there are three studies that have used the same sort of optical aid: (Lowe and Drasdo, 1992b, Drasdo and Murray, 1978, Szlyk et al., 1998b). Drasdo and Murray (1978) used monocular FE (or RTS) in five RP patients on a search task (discussed in Chapters 2 and 8). There was a significant difference between the monocular scores with the FE aid and those without it, however when the binocular scores with and without the
FE were compared to the scores with the monocular FE, no significant difference was found. Lowe and Drasdo (1992b) tested five RP patients with binocular FE on a search task (discussed in Chapters 2 and 8). The patients had done the search test in A-B-B-A (A refer to with aid and B refer to without the aid). They did not find a significant difference in search performance with or without the use of the binocular FE. In these two studies, the role of training was not explored (Drasdo and Murray, 1978) and sometimes was not possible because of switching from with the FE to without and vice-versa (Lowe and Drasdo, 1992b). This design possibly confused the patients and it might have been better if the patient had been trained to perform the search task with the FE. Further, the authors in these studies tried to compare the group performance with and without the device. However, this approach (discussed in Chapter 11) could mask any improvements that individual participants may show which could then lead to misinterpretation of the efficacy of the FE. We looked at the individual scores in these studies and found it to be true. For example Participants III and V, in Drasdo and Murray (1978), showed improvement in the time taken to complete the search task by 50%. However, this important finding was masked by the other three participants' scores. A similar finding was found in Lowe and Drasdo (1992b), where the BF subject scored better performance by 50% with the FE and this was also masked by the other participants' scores. The use of optical aids is a rehabilitation approach for individuals and therefore individual performance should be taken into account when assessing success or lack of it.

Szlyk et al. (1998b) is the third study of this kind of optical aid. Fifteen patients with RP were tested using the Amorphic telescope (discussed in Chapter 2, section 2.3.4) in its bioptic form. Orientation and mobility training, while wearing the aid, was conducted for
four weeks, each session lasting three hours. The training included locating objects, tracking stimuli, scanning skills and enhancing visual memory. The participants' performance was assessed by an O&M specialist. They reported improvement in functional vision as most of the visual skills improved by almost 40%. The greatest improvement was seen in mobility skills which improved by 45% and the lowest improvement was seen in scanning skills which improved by 25%. In addition, 86% of the patients reported an improvement in their visual skills which include recognition, peripheral detection, scanning, tracking, visual memory. The study results overall indicate a good success rate, however, in our study we did not have the same number of participants or the same amount of training to make a comparison. In addition, they used an O&M specialist in assessing the participants' performance, however these professionals are not available in every lab or clinic and such assessment is prone to subjective bias. In contrast we made use of the AVA test, which is objective and more adapted to a clinical setting.

In conclusion, some important points emerged from this study. First, participants appeared to adapt quite rapidly to the RTS and made noticeable improvements in the mobility course. The optical aids are not suitable for group use but were designed to respond to individual needs. The results found here also signify the importance of training. The AVA test was again shown to be useful in assessing optical aids for patients with TV.
13 Chapter Thirteen: Summary, Conclusions and Future Work
13.1 Summary and Conclusion

Patients with TV face challenges with navigation and obstacle avoidance (Haymes et al., 1996, Black et al., 1997, Turano et al., 1999b, Geruschat et al., 1998). The decline of mobility performance can markedly affect the individual's independence and QoL (Sugawara et al., 2010). One approach to improve mobility performance is the use of an optical aid.

Quantifying mobility performance is a challenging area facing researchers (Marron and Bailey, 1982). The difficulty stems from the fact that there is no universally accepted standard method of measurement. Suggested methods include assessment by using mobility courses, and the difficulties of designing a course are discussed in detail by Leat and Lovie-Kitchin (2006): all require the participants to walk quickly and without contacting any obstacles. However, mobility courses typically require a lot of space, which is not easily available in a clinical environment, and they also need to be easily replicated in different settings. In this study, a new, sensitive, short and easy to set up mobility course was designed and validated by real TVPs and SIPs. This represents a new approach to the construction of indoor mobility courses, and as it was also found to be easy to replicate in different settings, it is therefore a potentially useful tool for other studies and assessment situations.

Mobility is a complex task which involves visual, cognitive, oculomotor and limb elements (Fuhr et al., 2007). These elements are required to be combined while walking and mean that patients’ visual search performance is significantly linked to mobility performance (Kuyk et al., 1998, Bibby et al., 2007, Fuhr et al., 2007, Leat and Lovie-
Kitchin, 2008). This new test based on the visual search paradigm was therefore designed as an alternative to the mobility course. The main aim of this project was to develop a new clinical measure (the AVA test) that is valid, standardized, takes a short time to conduct and is more adaptable to a clinical/lab setting for assessing the efficacy of aids to enhance mobility performance in TV patients.

In this project several experimental studies were conducted while designing the AVA test, to ensure that the test is sensitive, challenging, and is not impacted by moderate VA and CS limitations. The AVA test was designed to assess the participants’ awareness of targets that appear within and outside the functioning VF. In developing this test we introduced changes that provide control over a number of variables: target locations, backgrounds and the use of head and eye movements, while maintaining test complexity. Further, this test records the DT of each target which allows assessment of any change in scores due to an intervention in relation to target eccentricity and direction. This test provides a much larger field in comparison to that produced using other devices such as UFOV and AFOV (Coeckelbergh et al., 2004, Kuyk et al., 2005). The overall time needed to complete the full programme of the AVA test is five to ten minutes, which is a reasonable time for a clinical test. Finally, the new test avoids the design constraints found in the studies by Lowe and Drasdo (1992b), Drasdo and Murray (1978) and Coeckelbergh et al. (2004).

The AVA test was validated using real patients and control participants. In order to simulate TV in control participants, special simulators were designed and validated. In our studies of the AVA test we found it responsive to changes in FoV size and to changes
in target locations in both participant groups. Further, a significant relationship was found between the participants' mobility performance and their AVA test performance. This result indicates that the AVA test is valid and that it could be used as an alternative to the mobility course.

In order to test the responsivity of the AVA test, participants completed the tests while using three different optical aids which are reported to enhance VF and improve mobility performance in TV patients. The AVA test was found to be responsive and provided indications of the efficacy of the optical aids in each participant. Interestingly, test results showed that two of these optical aids (the partial aperture prism and the Tri-field prism) were not found to be very efficient or helpful to TV patients. Previous studies of the use of the prisms were based on assessing visual functions (VA and VF) while wearing the optical aid, but this does not provide the clinician with the necessary information about the patient's performance in everyday activities. However, there was evidence to suggest the RTS is effective in enhancing the patient's VF and mobility performance, although it has the limitation of changing the perception of the objects' location.
13.2 Applications and Design Improvement of the AVA Test

The main application of the AVA test is its use in assessing the efficacy of optical aids to enhance the patient's mobility performance. This means that the test is not limited to the three optical aids used in this project but could be used with any aid proposed in the future. Further, this test could be used to assess optical aids suggested for other VF defects such as hemianopia, where the same situation that prompted the design of the AVA test applies. There are a number of optical aids available for hemianopia, but the majority have not been objectively evaluated. The exception is the Peli prism glasses, although these were assessed over prolonged wearing times. In the two heminaopic patients recruited in this project the efficacy of both the segment prism and the Peli prism were investigated, one prism type for each participant. There was an indication that the Peli prism improved the patient's performance in the AVA test, but as only one participant was recruited in this pilot study, a larger scale study is required.

The AVA test used in this project is portable and does not require a large space in a lab/clinical setting. The possibility of improving the design of the AVA test to be more portable seems to be limited. This is because projecting the AVA test on a VF bowl with chin rest would limit the use of head movements which can be a crucial compensatory behaviour in patients with VF defects. Further, presenting the test on a PC monitor would limit the display field and not allow us to present the targets at the 4th annulus or even at the 3rd annulus (depending on the viewing distance): it has been found in this study that the responses at these two locations have a significant relationship with mobility performance. In addition, viewing the PC monitor or the VF bowl from a shorter distance than the one used in this design may impact the number and size of the eye movements.
This is because eye movements have been found to be dependent on the viewing distance (Ono and Nakamizo, 1977). Therefore, this factor should be taken into account in any future study and the relationship between AVA scores and mobility course scores should be re-investigated. However, it might be feasible to develop a software program that would store the AVA "displays", present them in a random order and store the DT in order to use it instead of the visual stimulus generator (ViSaGe). This possibility could be explored in the future with the help of an experienced software engineer.

13.3 Research Limitations

In this research a number of important limitations need to be considered. These include using a monocular simulator, validating the AVA test by exploring the relationship between AVA scores and mobility performance on an indoor mobility course which we have designed, not being able to differentiate between good and poor performers using the IMQ, having a low success rate after the patients with TV used the prisms and finally the small sample size used in assessing the RTS efficacy.

The simulation of TV was a useful approach as it enabled us to recruit a large number of participants with no adaptation strategies to field loss and who had relatively good VA and CS. However, the only way we were able to simulate TV was using a monocular simulator, which impacts the viewer’s depth perception and gives participants additional challenges in judging obstacle distance. Further, the patients with TV could potentially compensate for their restricted field by making either head or eye movements. The SIPs, by contrast, could not use eye movements to improve their searching, but could use head movements, which are known to be slower. In future work it would be preferable to try to
find a method whereby the SIPs could view binocularly. A further potential limitation is the simulation of TV only in the RE. This means that the participant may potentially have difficulties in detecting a stimulus located towards the left side, in either the mobility course or in the AVA test. This effect would be observable in the AVA test scores if the DTs for the right side were much shorter than those for the left. However, we did not find any evidence of this effect when we explored the issue in the pilot analysis (not presented here as the data did not provide any additional insights). Although no effect was statistically observed, we would still suggest that if monocular simulation is used in any future studies, TV should be simulated in the RE of half of the sample and in the LE of the other half.

The second limitation was the challenge of finding a gold standard against which to compare the AVA test. In practice we designed and used a mobility course to validate the AVA test. The impetus for developing the AVA test was the current lack of an objective measure to assess the efficacy of optical aids for patients with TV. This of course means there is no existing measure against which to compare the AVA scores. But in several studies visual search performance has been strongly linked to mobility performance. Therefore, we tried to validate our new test by linking the AVA scores to the participants’ performance on an indoor mobility course. This created a second challenge which was that there was no standard indoor mobility course that could be replicated in our building and those suggested in the literature varied considerably in their designs. Therefore, we decided to design an indoor mobility course and use it to help validate the AVA test. In order to minimise any bias from our side, the potential usefulness of the mobility course was tested twice in the SIPs and in patients with TV before investigating the link between
their scores on the indoor mobility course and the AVA test. The term valid used in this thesis refers to the link between the participants' performance on the AVA test and on the mobility course. This limitation could impact the quality of validity evidence but not to the extent of invalidating the AVA test.

The third limitation was not being able to differentiate between good and poor performers using the IMQ. The idea was to divide the participants into two groups based on their IMQ scores and then relate this to their AVA scores. This was not possible, however, due to our inclusion criteria, which were restrictive because we aimed to recruit patients whose mobility was potentially compromised but who had good VA and thus benefit from the optical aids. Satisfying the IMQ hypothesis would have provided additional evidence of the potential sensitivity of the AVA test, and so there we missed an opportunity to affirm the AVA test sensitivity. In future studies, easing the inclusion criteria would be more appropriate. Additionally, recruiting patients with glaucoma who maintain a good VA level in the advanced stage would be recommended in order to be able to generalize the conclusion to a broader population. The AVA test showed some indication of its usefulness in patients with hemianopia, however, we were not able to recruit a substantial sample size, which was another limitation.

The fourth limitation of this research was the low success rate with the prisms. We had hoped that a significant number of participants would benefit from both prism types and that the AVA test would be able to predict this improvement. For those who noticed no change the AVA test would also show no change in their scores. Unfortunately, this was not the case since the vast majority of the participants did not find either of the prisms
useful. This was another missed opportunity to show the importance of the AVA test as measure for testing optical aid efficacy. The prisms were found to be unhelpful because of their inherent limitations: the Tri-field prism caused confusion and the partial aperture prism required active eye movements. In this way they are likely to have interfered with the TVPs’ existing compensatory strategies. These two prisms were unfortunately the only choice available to us at the beginning of the study since the RTS was not available in the UK at that time. In future studies more focus on the RTS is recommended as we found some indication of its usefulness.

In our study, RTS efficacy was tested with a small sample of users and there were indications that it has the potential to be an effective aid for patients with TV. However, our findings may not be representative of the wider population of TV patients and a future study using a much bigger sample size is recommended. Not being able to recruit a larger sample size in order to test RTS efficacy was due to the RTS becoming available in the UK only towards the end of the study and there was a scarcity of available TVPs who fulfilled the inclusion criteria.
13.4 Directions for Future Work

A number of studies can be suggested based on the results obtained from this project.

We found in this study that the AVA scores of the SIP and TVP groups were not very different to each other. It was expected that the TVPs would record shorter DTs because of their adaptation to the condition, but it is possible that the CS limitation in the TVPs might have masked this effect. Based on this, further studies could be conducted to explore the role of CS loss and adaptation independently on the AVA scores. This could begin by simulating CS loss in addition to FoV restriction in the control participants.

In this project we found statistical evidence to suggest that the RTS is helpful to TV patients. However, there were only a few TVP participants available for this particular study and the aid was not used over a long period of time. A future study with a larger sample size would clarify whether or not the RTS is a beneficial aid.

A future study could be conducted using the AVA to compare two different optical aids in the clinic, for either TV patients or hemianopic patients, in order to investigate if there is a marked difference between them. This would aid prescribing decisions.

The AVA test could also be used as a rehabilitation approach by training patients to perform the scanning search. This approach might encourage TV patients to increase the number/size of eye movements (monitored by an eye tracker). This in turn could lead to improvement in mobility performance. A further study could be conducted to explore the effect of scanning training on mobility performance.

While it appears intuitive that improved scanning in TV patients is a useful strategy to
improve performance, Vargas-Martín and Peli (2006) and Luo et al. (2008) have reported no difference between TV patients and normally sighted participants in eye movements and saccadic sizes and directions while walking. However, this does not explain how some TV patients are better than others (TVP or SIP) who are matched in terms of VA and VF, as found in this project; or how some TV patients can match the performance of normally sighted subjects in everyday activities (some of the patients travelled to Manchester alone, using public transport). Therefore, the AVA test could be used to explore the differences in eye movement search strategies (if any) in a sample of TV patients, comparing them to normally sighted subjects.
References


BERSON, E. 1993. Retinitis-Pigmentosa - the Friedenwald Lecture. *Investigative Ophthalmology*


Remediation and Management of Low Vision. St. Louis; m.


FUKUDA, S., OKAMOTO, F., YUASA, M., KUNIKATA, T., OKAMOTO, Y., HIRAOKA, T. & OSHIKA, T.


HOLM, O. 1970. A simple method for widening restricted visual fields. Archives of


LOVIE-KITCHIN, J., MAINSTONE, J., ROBINSON, J. & BRIAN, B. 1990. What areas of of the visual field are important for mobility in low vision patients? *Clinical Vision Sciences*, 5, 249-263.


Rheumatology, 25, 1681-1686.


PERLIN, R. & DZIADUL, J. 1991. Fresnel prisms for field enhancement of patients with constricted
or hemianopic visual fields. *Journal of the American Optometric Association*, 62, 58-64.


Appendix One
UNIVERSITY OF MANCHESTER

COMMITTEE ON THE ETHICS OF RESEARCH ON HUMAN BEINGS

Application form for approval of a research project

This form should be completed by the Chief Investigator(s), after reading the guidance notes.

1. Title of the research
Full title: A study to develop a new clinical measure to evaluate the visual field awareness in a tunnel vision population.

2. Chief Investigators

Title: Professor Mr.
Forename/Initials: Chris Ali
Surname: Dickinson Al Shaghthrah
Post: Professor of Clinical Optometry Postgraduate Research Student
Qualifications: BSc. PhD MCOptom BSc.
School/Unit: Faculty of Life Science
E-mail: chris.dickinson@manchester.ac.uk Ali.Alshaghthrah@postgrad.manchester.ac.uk
Telephone: +44 (0)1613063874 Tel: +44 (0)7719727488
Fax: +44 (0)1613063887

3. Details of Project

3.1 Proposed study dates and duration
Start date: 1/6/2010
End date: 1/9/2013

3.2 Is this a student project?
✓ Yes/No

If so, what degree is it for?
MPhil/PhD
3.3. What is the principal research question/objective?
(Must be in language comprehensible to a layperson.)

The main objective of the study is to develop a measure of the effectiveness of an optical device in allowing detection of objects in the non-seeing area of the visual field, which will only take a few minutes to carry out and is practical in a clinical setting. A review of the literature has suggested that this measure should be based on a visual search task. The validity and sensitivity of this measure will be evaluated by determining how well it correlates with the short-term and long-term success of rehabilitation using the optical aid in the real world setting over a prolonged period.

3.4. What is the scientific justification for the research? What is the background?
Why is this an area of importance / has any similar research been done?
(Must be in language comprehensible to a lay person.)

Retinitis pigmentosa (RP) is an ocular disease which affects the light-sensitive cells in the eye and causes them to progressively degenerate over a long period of time (Hamel, 2006). The prevalence of RP is commonly believed to be 1 in 4000 people (Hamel, 2006, Hartong et al., 2006, Berson, 1993), with the number of RP patients worldwide reaching approximately 1 – 1.5 million people (Berson, 1993, Hartong et al., 2006). RP currently has no medical/surgical treatment that can stop the progression or restore vision. In the early stages patients report night-blindness and, as the disease progresses, there is loss of the visual field (VF) such that sufferers no longer see objects to the sides. In the advanced stage the patient will lose most of his/her visual field and will retain only a few degrees of the central field of view (so-called “tunnel vision”). This will inevitably cause some activity limitations even though visual acuity remains high.

Patients with restricted field most commonly complain of limitations with orientation and
mobility (Pelli, 1987a). Mobility can be defined as the physical ability to systematically navigate from one place to another one, independently, safely, and comfortably (Dickinson, 1998). Mobility affects the level of independence which is a crucial element of the quality of life of the patient. According to Turano et al. (1999a), the five most difficult mobility situations that RP patients confront are: walking at night, moving about in crowded places, avoiding bumping into low-level objects, adjusting to lighting changes during the day (outdoor to indoor), and walking in dimly lit indoor areas. These five situations reflect the three common clinical features of RP: loss of VF, night blindness, and difficulty to adapt to light changes (Geruschat and Turano, 2002).

There are a limited numbers of spectacle-mounted optical aids (Holm, (1970), Onufryk (1994), Woods et al., (2010b)) that have been suggested to enhance the field of view. These are designed to minify and/or deflect the image from the non-seeing areas and move it to areas which are still functioning, with the aim of improving the ability to move in crowded places and avoid contact with other people or objects. These optical aids include the reverse telescope (Holm,(1970)), In-wave prism (Onufryk, (1994), and recently the trifield prism (Woods et al., (2010b). However, the effectiveness of these optical aids is largely based on subjective measures, usually the patient and/or clinician decide that the device should continue to be worn after a trial period. Success is rarely based on any measured improvement of mobility performance, and can only be judged after several weeks of wear.

The main aim of this study, therefore, is to develop a test which will determine the effectiveness of an optical device in allowing detection of objects in the non-seeing area.
of the visual field, and which will only take a few minutes to carry out within a clinical setting. A review of the literature has suggested that this measure should be based on a visual search task. Visual search is often tested by asking a subject to detect, localize, and identify a selected target against a complex background (Ball et al., 1988b). It is believed that all these elements are involved in everyday mobility (Kuyk et al, 2005). When walking, it is important to direct one’s eyes to objects of interest to be localized, identified, and perhaps avoided (Fuhr et al., 2007). The time taken to notice the obstacle may influence mobility performance (Kuyk et al., 2005). For instance, using a 20 degree visual field, Fuhr and colleagues (Fuhr et al., 2007) concluded that up to 66.9% of the variation of mobility performance could be accounted for by reaction time for peripheral objects. However, eye and head movement were not allowed during the trial in order to prevent the participant from using eye and/or head scanning skills he/she had developed to compensate for the field loss.

Coeckelbergh (2004) therefore introduced the concept of “attended field of view” to evaluate the efficiency of the search behaviour. In this test head and/or eye movements were permitted, which allowed the patients to use any compensatory viewing techniques they typically used. However, the background of the visual test was not complex enough to represent the complexity of the typical environment.

This is the basis on which our awareness test was developed. This study will aim to assess the validity and sensitivity of this measure in a number of ways.

Validity will be established by showing a correlation between performance on the test and:
1. the degree of visual field available to normal participants with simulated impairment of 
the visual field (SIP) (expecting that smaller field = poorer performance);

2. performance of tunnel vision patients (TVPs) and SIPs (while wearing various 
simulated field constricting devices) on an indoor mobility course;

3. real life mobility skills of TVPs as measured by a previously validated mobility 
questionnaire (Turano et al.1999a) and

4. the TVPs score on Low Vision Quality-of-Life Questionnaire (LVQOL) which has 
been previously validated (Wolffsohn and Cochrane, 2000).

Sensitivity will be measured by looking for:

1. a change in performance on the test with the use of optical devices designed to 
improve the mobility of TVPs and

2. better performance from a TVP who is well adapted to their condition compared to one 
who is poorly adapted; or compared to a SIP.

Repeatability of the test will also be determined.

A secondary aim will be to investigate the usefulness of specialist optical devices in 
TVPs. The experiments to address these aims will be described in detail in the method 
section (section 3.6). An additional approach will be used to assess the validity and 
sensitivity of the awareness test.

A second control group will be recruited in order to test their scores in the awareness test. 
This control group will have hemianopia, which is a loss of vision in either the right or 
left sides of both eyes. This condition is a common side effect of stroke or brain injury. 
However, the patient will be recruited in the study only if they are physically and 
mentally healthy. The participants will do the visual awareness test twice, once with their 
habitual glasses (if any) and again with the Peli Prism Lens (Peli, 2000) (a prism that can 
be fitted over the glasses in order to shift the image toward the functioning field of view).
The purpose of recruiting this group is to show that the awareness test’s detection time (DT) will be significantly faster on the functioning side in comparison to the non-functioning side. In addition, the awareness test result may show the DT is significantly faster when the Peli prism glasses are worn while doing the test. Finally, a good correlation might be found between the awareness test score and the participants’ mobility scores which could provide a further evidence of the validity of the awareness test.

References


3.5. How has the scientific quality of the research been assessed?(Tick as appropriate)

☐ Independent external review
☐ Review within a company
☐ Review within a multi-centre research group
☐ Internal review (e.g. involving colleagues, academic supervisor)
☐ None external to the investigator
☐ Other, e.g. methodological guidelines (give details below)

If relevant, describe the review process and outcome.
If the review has been undertaken but not seen by the researcher, give details of the body which has undertaken the review:

N/A

3.6. Give a full summary of the purpose, design and methodology of the planned research, including a brief explanation of the theoretical framework that informs it. It should be clear exactly what will happen to the research participant, how many times and in what order. Describe any involvement of research participants, patient groups or communities in the design of the research. (This section must be completed in language comprehensible to the lay person.)

**Purpose:** The development of a new clinical measure to evaluate the awareness of peripheral objects in the visual field, and evaluation of the validity, sensitivity and repeatability of this proposed measure in a tunnel vision population (i.e. patients with RP). This will be undertaken with a series of experiments which will take place at the Vision Centre, Carys Bannister building, University of Manchester, M13 9PL.

**Method:**
**The proposed new awareness test:**

A Matlab computer program was developed to test the observer’s visual awareness of, and their ability to look for, objects off to the side in all directions. The visual display (projector screen) consists of a uniform gray background (or noise background).

Superimposed on this background, the display will contain a central coloured cross
(always in the same location) and a black and white square that will be presented in one of 32 different positions (see Apx1. Figure1 below). The possible positions of the square were divided into four main locations. These are: central (within the central 5° radius of the field of view and numbered from 1-8), inner annulus (from 5°-20° radius and numbered 9-16), outer annulus (from 20°-40° radius and numbered from 16-23), and peripheral (at the edge of the 60° field of view and numbered from 24-32).

Apx1. Figure 1. The background scene used in the test with the colour cross that will be presented, shown in one of the 28 possible positions.

The sequence of the slide will be as follows: the background slide will be continuously presented as a default background, the central and peripheral targets will be presented in random order. The participant will be asked to identify the central target (whether it is a red or blue cross presented in the centre of the display) and search for and locate the square, which could be anywhere within the background. The subject will be informed that head and eye movements are allowed. The participant will be asked to immediately press a mouse button as soon as they have noticed the eccentric target. The response time will be automatically recorded and sent to an Excel spreadsheet. A break slide will be presented (the default background) during which the participant is asked to report the
colour of the central cross and the position of the presented stimulus. The score that is collected will include accuracy of location of the coloured square, and the response time for targets accurately located by direction (if the target direction is inaccurate the response time will not be counted). The same procedure will be repeated for the next 27 slides that will be used to test the other meridian positions.

The visual display will be projected by a Hitachi CP-AW100N multimedia mobile LCD projector. This will provide a total stimulus area of about 80° horizontally at 120cm.

**Indoor mobility course:**

The course is divided into three phases. In the first phase, the subject will be asked to walk for 20 metres from one point to another in a straight-line at his/her normal pace, and will be informed that there will not be any obstacles obstructing their path. This phase is designed in order to determine the preferred walking speed over the shortest practical distance. In the second phase, which is the main mobility course and designed to evaluate the subject’s ability to travel independently, the participant will be asked to walk 40 metres, but obstacles will be randomly distributed approximately every one metre and will be varying in their size, height, and contrast (the obstacles will be made from foam, soft cardboard, or polystyrene). This course has to be long enough to include a sufficient number of potential interactions. The number of contacts, with the obstacles, and the time taken to travel the path will be recorded. The latter will be recorded as percentage preferred walking speed (PPWS) by comparison with PWS. This ratio measure has been used in many studies and allows us to control for individual fast and slow walkers.

In the third phase, the subject will be asked to walk for 20 metres, on an unobstructed
route, although this time attempting to notice targets which have been placed to the side of the travel path. This phase is designed to determine the mean visual detection distance (VDD = the distance from the participant to the obstacle when they notice it).

**Mobility questionnaire:**

A well established questionnaire devised to evaluate mobility performance in an RP population will be used in this study for two purposes. Firstly, to try to categorize the TVPs into ‘well adapted’ and ‘poorly adapted’ subjects, and secondly to evaluate the long-term usefulness of the optical aids that are trialled with the TVPs. The questionnaire that will be used is the thirty five item Independent Mobility Questionnaire (IMQ) which was introduced by Turano et al. (1999a). The patient is asked to rate the difficulty in each situation (from 1 to 5, where 1 refers to no difficulty and 5 extreme difficulty). The questionnaire is the only available questionnaire at the present time that is solely directed toward the task and the population that we have targeted. The questionnaire has been shown to be well constructed, valid, and highly reliable for assessing independent mobility in RP and glaucoma patients.

Low Vision Quality-of-Life Questionnaire (LVQOL)

An established questionnaire designed to evaluate the low-vision rehabilitation strategy and management will be used in this study. The LVQOL (Wolffsohn and Cochrane, 2000) consists of 25-items sub-scaled into four main domains. These are:

1. Distance vision, mobility, and lighting,
2. Adjustment,
3. Reading and fine work, and

The LVQOL has a high internal consistency (α = 0.88) and good reliability (0.72) and has been considered as a good method for measuring the vision-specific quality of life of the visually impaired in a clinical setting. The patient is asked to rate the difficulty in each situation (from 5 to 1, where 5 refers to no difficulty and 1 extreme difficulty). In addition, the participants can skip the question if they can no longer perform the task due to a reason related to their vision or to a reason not related to their vision, using X for vision limitation and n/a for other reasons.

The LVQOL structure will allow us to establish the comparison between the TVPs score on each subscale (especially these ones that have less association with mobility performance) and the TVPs awareness test score in order to provide additional evidences of the validity of the awareness test while taken into account the TVPs on the IMQ.


Simulated field loss:

Patients with tunnel vision represent a very variable group, even if the cause of the defect
is the same in most cases. Patients will show different levels of adaptation to their loss, and some may have additional visual defects (e.g., poor ability to detect low contrast).

In order to be able to test systematically the effect of precisely defined field defects, we will also test normally sighted participants using simulated field loss (SIP). This represents our control group. Two methods of generating overall field constriction will be used: goggles for non-spectacle wearers or a clip-on lens for spectacle wearers to reduce the field of view to a 5°, 10°, 15°, and 20° remaining field of view. Pilot experiments have shown that the methods of simulating field loss are equivalent. The test will be carried out monocularly (because of the constraints of the simulators) and the right eye will always be used unless it has significantly worse visual acuity than the left eye.

**Pre-assessment tests:** Initial optometric clinical tests will be performed to collect background data and established eligibility. These tests will be as the following:

Distance logMAR binocular visual acuity (VA), scored by letter, with habitual spectacles or contact lenses. If the participant is not using spectacles or contact lenses, or if these are more than one year old, the subject will be tested to confirm the up-to-date prescription.

Log contrast sensitivity will be measured binocularly using the Pelli-Robson chart at 200 cd/m2 luminance at a viewing distance of 1 metre to determine the sensitivity of the subject to low contrast objects.

The remaining extent of the binocular visual field will be measured in tunnel vision patients using the Aimark manual kinetic perimeter. This will also be used for SIP wearing one of the field restricting lenses to confirm the effect (this will allow the field
restriction of the other apertures to be calculated).

The TVP will have their adaptation graded using the IMQ.

The TVP quality of life will be tested with the LVQOL.

The first three tests will be performed binocularly since the awareness measure and the indoor mobility course will be assessed binocularly and also because we want to evaluate the TVPs functional performance in his/her everyday life. The SIP will have these tests repeated monocularly to establish which eye will be used for the subsequent experiments.

**Plan of visits:**

**Visit one:** All participants will undergo pre-assessment tests and then the new awareness test. The SIP group will perform the test while using the four different levels of simulated visual field constriction in decreasing order of field size. The SIPs performance on the indoor mobility course will also be evaluated at this visit.

The TVP group will perform the test binocularly wearing their habitual spectacles or contact lenses.

Hemianopic participants will do the awareness test and mobility course with and without Peli prism lens.

**Visit two:** SIPs will be invited to return to repeat the experiment in order to obtain data on test repeatability.

The performance of the TVPs in the awareness test will be repeated. Then the peripheral
visual field will be measured using the Aimark perimeter while wearing an optical device designed to improve visual field in tunnel vision patients: either the In-wave prism system (Onufryk M., 1994) or the Tri-field field prism (Woods et al., 2010b) (to be selected at random). The awareness test will be repeated with this device in place. The performance on the indoor mobility course will also be evaluated before, and then while, wearing the optical aids (having adapted to them for about 30 minutes).

At the end of this visit the TVP will be invited to take the aid away and use it as much as possible in everyday circumstances over a period of 4-8 weeks. If they agree to this, they will return for a third visit to assess long-term success.

**Visit three:** For TVPs wearing an optical aid, the awareness test and indoor mobility test will be repeated with and without the aid. The IMQ and the LVQOL will also be repeated.

3.6.1. Has the protocol submitted with this application been the subject of review by a statistician independent of the research team? (Select one of the following)

- Yes – copy of review enclosed
- Yes details of review available from the following individual or organisation (give contact details below)
- No – justify below

No complex statistical techniques will be involved. The final stages of the project will be carried out with small numbers of participants and are in the form of a pilot study/case series.

3.6.2. If relevant, specify the specific statistical experimental design, and why it was
chosen?

The student t-test will be used in the awareness test experiments to assess mean differences between groups. The Spearman correlation coefficient will be used to determine relationships with other measures. This has been chosen because it applies to ordinal variables and does not require normally distributed variables.

A Bland-Altman analysis of the Visit 1 and 2 awareness test scores for both SIP and TVP will be carried out to establish 95% confidence limits for agreement.

**Hypotheses to test:**

SIP awareness test score will be directly correlated with (and predictable from) the extent of the simulated visual field. The score will vary linearly with eccentricity, with response time being progressively longer as targets become more peripheral.

TVPs awareness test score will be better than that of SIPs with equivalent field loss because the patients with ‘real’ defects are well-adapted to their loss. If patients are graded as ‘well-adapted’ or ‘poorly-adapted’ (i.e. with few problems, or with severe problems, with mobility, respectively) on the basis of their score on the IMQ, it would be expected that the awareness test score will be better in the well adapted subject. Additionally, the awareness test score would be expected to correlate with the PPWS and the VDD score on the indoor mobility course.

Both of these results will indicate that the new awareness test is valid.

When using optical aids the awareness test scores of well-adapted TVP will not improve
as much, or may even decrease, whereas the poorly adapted patient would have a greater improvement. This is because the aids would not help, or may hinder, patient who already adopted various eye and head movement strategies to enable them to perform every day activities safely.

The validity of the awareness test as a predictor of long-term rehabilitation success will be further assessed using correlation of the change in awareness test score when wearing the aid initially, with the change in IMQ score, LVQOL score and indoor mobility course performance, after using the aid for several weeks.

Hemianopic participants’ awareness test DT will be much faster on the functioning side in comparison to the non functioning side. In addition, the DT score will might be faster with Peli lens in comparison to the score without using any optical aid. Both results could indicate that the test is sensitive and valid.

3.6.3. How many participants will be recruited?
If there is more than one group, state how many participants will be recruited in each group. For international studies, say how many participants will be recruited in the UK and in total.

We are planning to recruit up to 50 control participants and up to 34 participants (retinitis pigmentosa and choroideraemia). Up to 10 Hemianopic participants will be recruited as a second control group for our study.

3.6.4. How was the number of participants decided upon?

If a formal sample size calculation was used, indicate how this was done, giving
sufficient information to justify and reproduce the calculation.

The power calculation (G*Power Version 3.0.10) was based on detecting a difference in a two-tailed t-test (medium effect size (0.5) significant at 0.05 level with 80% power) in awareness test score for TVPs with and without an optical aid. This suggested a sample size of 34. The sample size would be equivalent for the repeatability studies: the number of control subjects recruited is larger because we assume they will be less willing to return for the second visit.

3.6.5. Describe the methods of analysis (statistical or other appropriate methods, e.g. for qualitative research) by which the data will be evaluated to meet the study objectives.

A quantitative analysis will be used with statistical comparisons of means and correlations as described above.

3.7. Where will the research take place?

The University of Manchester, Carys Bannister Building

3.8. Names of other staff involved.

None

3.9. What do you consider to be the main ethical issues which may arise with the proposed study and what steps will be taken to address these?

There is no ethical issue which may arise for the control participants. However, the RP participants may feel disappointed with any lack of beneficial effect with the optical devices. However, a clear description of the test and the overall idea behind the study will be given in the patient information sheet (PIS) to try to make it clear that this is not a treatment study.
3.9.1. Will any intervention or procedure, which would normally be considered a part of routine care, be withheld from the research participants?

☐ Yes  ✓ No

4. Details of Subjects.

4.1. Total Number

94 participants

4.2 Sex and Age Range

No gender restriction, 18 years to 65 years

4.3 Type

The SIP group are likely to be university staff and students.

4.4. What are the principal inclusion criteria? (Please justify)

The following are the criteria for the inclusion of participants to the experiments:

**Control subjects:**

1. Normal visual functioning (i.e. central visual acuity better than 6/9 with latest prescription in at least one eye, corrected with ordinary spectacles or contact lens).
2. The general physical ability to perform the proposed test(s) (will be decided based on the history taking from the subject).
3. No history of ocular disease.

**Hemianopic participants** should be formally diagnosed with the condition. Satisfactory levels of physical and mental ability will be decided based on the history taking from the subject. Normal visual functioning (i.e. vision level better than 6/18 with best correction at least in one eye with ordinary spectacles or contact lens).

**RP Subjects:** The patient should be formally diagnosed with retinitis pigmentosa, or choroideraemia, with remaining visual field of 20° or less (i.e. confirmed by binocular
Aimark functional visual field plot and/or bjerrum visual field plot) in order to be within the visual field range to be simulated in the control group.

Normal visual functioning (i.e. central visual acuity better than 6/18 with best correction at least in one eye with ordinary spectacles or contact lens) in order to try to avoid the negative influence of the optical aid on the visual acuity.

The physical ability to perform mobility (walking) test(s) will be decided based on the history taking from the subject.

4.5. What are the principal exclusion criteria? (Please justify)

Exclusion criteria:

1. Non-English speaker; because the IMQ and the LVQOL is only available in English and this may also influence the communication between the examiner and the participant during the experiment(s).

2. Poor hearing to the extent that normal conversation is not possible; because the patient would not be able to hear the experiment procedure and the instruction(s).

3. Any disability, including the learning disability, to extent that it may prevents the patient from independent living or moving about. That is because the study involves a mobility questionnaire which requires the answers to be influenced by vision rather than other factors.

4. Migraine sufferers or epileptic patients, because the study involves flashing bright targets that may negatively influence those participants.
4.6. Will the participants be from any of the following groups? (Tick as appropriate)

- Children under 16
- Adults with learning difficulties
- Adults who are unconscious or very severely ill
- Adults who have a terminal illness
- Adults in emergency situations
- Adults with mental illness (particularly if detained under mental health legislation)
- Adults with dementia
- Young offenders
- Adults in Scotland who are unable to consent for themselves

☑ Healthy volunteers
- Those who could be considered to have a particularly dependent relationship with the investigator, e.g. those in care homes, medical students.

☐ Other vulnerable groups

Justify their inclusion

No vulnerable groups will be included in the study. The main two groups that will be included are healthy volunteers to act as a control group and retinitis pigmentosa patients.

The study is investigating an intervention aimed specifically at this patient group.

4.7. Will any research participants be recruited who are involved in existing research or have recently been involved in any research prior to recruitment?

☐ Yes ☐ No ☑ Not known

If Yes, give details and justify their inclusion. If Not Known, what steps will you take to find out?

It would not be relevant to their involvement in this study.

4.8 How will potential participants in the study be (i) identified, (ii) approached and (iii) recruited?

Where research participants will be recruited via advertisement, please append a copy to this application
Methods to recruit control participants:

Advertisement poster (copy attached) in Carys Bannister Building and elsewhere on university campus and an announcement email will be sent via the university announcement service to call for healthy participants.

Methods to recruit RP participants:

Patients attending University of Manchester Low Vision Clinic will be given an information sheet about the study by the principal investigators; an announcement email will be sent via the university announcement service to call for participants with tunnel vision who may study at the university, an email will be sent including invitation to the member of RP group over the face book website (copy attached). The RP groups that will be invited will include, Retinitis Pigmentosa Support Group, Retinitis Pigmentosa Awareness Campaign/Petition, RP Fighting Blindness (BRPS) information and support group, Retinitis Pigmentosa Group (three groups with the same name), Foundation Fighting Blindness group, Retinitis Pigmentosa and Me group, I Support the Foundation Fighting Blindness!! group, Friends with RP (retinitis pigmentosa) /Vision Challenges group, and the British Retinitis Pigmentosa Society (BRPS) group, and advertisements will be published at a number of the local newspapers (the advert words that will be used are the same as those used in recruiting the RP patients via the university announcement service).
4.9 Will individual research participants receive reimbursement of expenses or any other incentives or benefits for taking part in this research?

☑ Yes  ○ No

If yes, indicate how much and on what basis this has been decided

Travel expenses will be refunded for each time the participant came to our lab to be a part of our experiments. In addition, £15 will be paid to each participant of the control group and £25 to the RP and the Hemianopic participants for each time the participant attends our lab. The amount of money is based on the expected length of the visits in each case.

5 Details of risks

5.1 Drugs and other substances to be administered

Indicate status, eg full product licence, CTC, CTX. Attach: evidence of status of any unlicensed product; and Martindales Pharmacopoeia details for licensed products

<table>
<thead>
<tr>
<th>DRUG</th>
<th>STATUS</th>
<th>DOSAGE/FREQUENCY/ROUTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.2 Procedures to be undertaken

Details of any invasive procedures, and any samples or measurements to be taken. Include any questionnaires, psychological tests etc. What is the experience of those administering the procedures?

A visual function questionnaire which is directed to mobility task consist of 35 mobility situation (IMQ) will be administered. and a Low Vision Quality-of-Life Questionnaire (LVQOL) consist of 25 items will also be administered. The examiner, Ali M. Alshaghthrah, will administer the questionnaire. The examiner is a qualified optometrist in the Kingdom of Saudi Arabia and has five years clinical experience. The questionnaire
will be administered verbally to the individual participant in private.


5.3 Activities to be undertaken

Please list the activities to be undertaken by participants and the likely duration of each

1. Pre-assessment tests at first visit: 30 minutes
2. Completing a questionnaire on patients’ mobility activities: 15 – 20 minutes.
3. Performing the awareness test: 20–30 minutes.
4. Performing a mobility task which will require participants to walk in an indoor environment at three different routes: 30 minutes.

5.4 What are the potential adverse effects, risks or hazards for research participants, including potential for pain, discomfort, distress, inconvenience or changes to lifestyle for research participants?

There are no direct risks or hazard associate with this study. However, the subject may accidentally contact the obstacles in the mobility course. For that reason, the obstacles are made from materials that will not affect the patient (foam, soft cardboard, or polystyrene). Finally, visits will take place at a time that is suitable for the patient.

5.5 Will individual or group interviews/questionnaires discuss any topics or issues that might be sensitive, embarrassing or upsetting, or is it possible that criminal or other disclosures requiring action could take place during the study (e.g. during interviews/group discussions, or use of screening tests for drugs)?

☑ Yes  ☐ No

If yes, give details of procedures in place to deal with these issues:

The patient may feel slight distress from being asked to identify their difficulties when
answering the mobility questionnaire. They can stop the interview at any stage, or refuse to answer any question. Details of the RNIB or BRPS telephone helpline can be provided if required.

5.6 What is the expected total duration of participation in the study for each participant?

All participants are expected to attend at our lab for at least two visits (each visit is expected to last between 30 minutes to 2 hours).

5.7 What is the potential benefit to research participants?

There are no direct benefits to the participants, however, the RP participants may gain benefit from the proposed optical aid and may choose to continue to wear it. No charge will be made for any optical aids.

5.8 What is the potential for adverse effects, risks or hazards, pain, discomfort, distress, or inconvenience to the researchers themselves? (If any)

There are no adverse effects to the researcher

6. Safeguards

6.1 What precautions have been taken to minimise or mitigate the risks identified above?

The participant has the right to stop the experiment at any time to have a break and has the right to not answer on selected items of the questionnaire if they prefer. Finally, the patient can withdraw from the study at any time without giving a reason.

6.2 Will informed consent be obtained from the research participants?

✓Yes ☐ No
If Yes, give details of who will take consent and how it will be done. Give details of the experience in taking consent and of any particular steps to provide information (in addition to a written information sheet) e.g. videos, interactive material.

If participants are to be recruited from any of the potentially vulnerable groups listed in Question 4.6, give details of extra steps taken to assure their protection. Describe any arrangements to be made for obtaining consent from a legal representative. If consent is not to be obtained, please explain why not.

Where relevant the committee must have a copy of the information sheet and consent form.

The principal investigators will give the potential participant an information sheet and informed consent form at their attendance at the university clinic or via the post/E-mail if the patient was recruited through any of the announcements we have distributed.

The principal investigators are qualified optometrists so are accustomed to seeking consent for clinical procedures.

6.3 Will a signed record of consent be obtained?

✔ Yes  ○ No

If not, please explain why not.

6.4 How long will the participant have to decide whether to take part in the research?

The participant will be given two weeks to decide whether to take part in the research. After two weeks the investigator will send a letter either by an email or by post asking if they have further questions regarding their participation. Once they have agreed and the consent has been obtained the investigator will contact the participant in order to arrange a time that suit them to perform the tasks. Initially, two appointments will be scheduled for each participant, however these appointments are flexible and can be changed based
on the subject’s needs

6.5 What arrangements have been made for participants who might not adequately understand verbal explanations or written information given in English, or who have special communication needs? (e.g. translation, use of interpreters etc.)

People who cannot communicate verbally in English will not be part of the study.

The RP patients who will be recruited are partially sighted; therefore a full verbal explanation of the experiment will be used to back up the written information. For those who have a learning disability, but not to an extent to affect their ability to live independently, their understanding of the task and the consent process will be assessed by asking them questions about it as a part of the process of obtaining consent.

6.6 What arrangements are in place to ensure participants receive any information that becomes available during the course of the research that may be relevant to their continued participation?

Any information that is relevant to their continued participation will be sent to them by post or email.

6.7 Will the research participants’ General Practitioner be informed that they are taking part in the study?

☐ Yes ☒ No

If No, explain why not

The experiment will solely depend on the awareness test, a mobility questionnaire, and a mobility course. The findings of the research would not be directly affected the patient’s health or well-being.
6.8 Will permission be sought from the research participants to inform their GP before this is done?

☐ Yes ☑ No

If No, explain why not

N/A

6.9 What arrangements have been made to provide indemnity and/or compensation in the event of a claim by, or on behalf of, participants for (a) negligent harm and (b) non-negligent harm?

The study will take place after gaining the approval by the University of Manchester Committee on Ethics of Research on Human Beings. The University has an insurance policy that covers negligent and non-negligent harm.

7. Data Protection and Confidentiality

7.1 Will the research involve any of the following activities at any stage (including identification of potential research participants)? (Tick as appropriate)

☑ Examination of medical records by those outside the NHS, or within the NHS by those who would not normally have access

Electronic transfer by magnetic or optical media, e-mail or computer networks

Sharing of data with other organisations

Export of data outside the European Union

☑ Use of personal addresses, postcodes, faxes, e-mails or telephone numbers

Publication of direct quotations from respondents

Publication of data that might allow identification of individuals

Use of audio/visual recording devices

☑ Storage of personal data on any of the following:

☑ Manual files including X-rays
NHS computers

Home or other personal computers

✔ University computers

Private company computers

✔ Laptop computers

Further details:

Examining the patient records at the University Low Vision Clinic is necessary to obtain some basic information such as visual acuity, VF, or contrast sensitivity. The use of the patient personal information will be necessary in order to contact the patient to inform them about the study. Names and contact details will be provided by the control group volunteers themselves.

7.2 What measures have been put in place to ensure confidentiality of personal data? Give details of whether any encryption or other anonymisation procedures have been used and at what stage?

Subjects recruited to the study will be assigned a unique identification code. All analysis will be undertaken using the identification code. Original documentation will be locked in a secure cabinet. Analysis will be undertaken on a personal computer that will be password protected; no personal identification will be used within the statistical analysis programs.

7.3 Where will the analysis of the data from the study take place and by whom will it be undertaken?

The analysis of the data will take place at the University of Manchester (either on the university computer of the principal investigator and/or the educational supervisor which will be password protected). The analysis will be carried out by the principal investigator
(Ali M. Alshaghtrah) and/ or the educational supervisor (Prof. Chris Dickinson).

7.4 Who will have control of and act as the custodian for the data generated by the study?

The principal investigator and/ or the educational supervisor will keep the data and will maintain its confidentiality.

7.5 Who will have access to the data generated by the study?

The principal investigator and/ or the educational supervisor will have the access to the data generated by the study.

7.6 For how long will data from the study be stored?

7 Years 0 Months

Give details of where they will be stored, who will have access and the custodial arrangements for the data:

The generated data will be stored in the principal investigator’s university office and it will be accessed by the principal investigator and/ or the educational supervisor. After the graduation of the principal investigator the data will be saved on a CD and kept in locked storage by the educational supervisor.

8. Reporting Arrangements

8.1 Please confirm that any adverse event will be reported to the Committee

I confirm that any adverse event will be reported to the committee
8.2. How is it intended the results of the study will be reported and disseminated?  
(Tick as appropriate)

☑ Peer reviewed scientific journals

Internal report

☑ Conference presentation

☑ Thesis/dissertation

Written feedback to research participants

Presentation to participants or relevant community groups

☑ Other/none e.g. Cochrane Review, University Library

8.3 How will the results of research be made available to research participants and communities from which they are drawn?

A report of the study finding after the end of the project will be sent to the participants and/or the groups/organization they were recruited from.

8.4 Has this or a similar application been previously considered by a Research Ethics Committee in the UK, the European Union or the European Economic Area?

☐ Yes ☑ No

If Yes give details of each application considered, including:

Name of Research Ethics Committee or regulatory authority:
Decision and date taken:
Research ethics committee reference number:

8.5 What arrangements are in place for monitoring and auditing the conduct of the research?

Regular contact with the research educational supervisor.

Will a data monitoring committee be convened?

☐ Yes ☑ No
What are the criteria for electively stopping the trial or other research prematurely

N/A

9. Funding and Sponsorship

9.1 Has external funding for the research been secured?

☐ Yes ☑ No

If Yes, give details of funding organisation(s) and amount secured and duration:

9.2 Has the external funder of the research agreed to act as sponsor as set out in the Research Governance Framework?

☐ Yes ☐ No ☑ Not Applicable

9.3 Has the employer of the Chief Investigator agreed to act as sponsor of the research?

☑ Yes ☐ No

9.4 Sponsor (must be completed in all cases where the sponsor is not the University)

The University of Manchester

10. Conflict of interest

10.1 Will individual researchers receive any personal payment over and above normal salary and reimbursement of expenses for undertaking this research?

☐ Yes ☑ No

If Yes, indicate how much and on what basis this has been decided:

10.2 Will the host organisation or the researcher’s department(s) or institution(s) receive any payment of benefits in excess of the costs of undertaking the research?

☐ Yes ☑ No
10.3 Does the Chief Investigator or any other investigator/collaborator have any direct personal involvement (e.g. financial, share-holding, personal relationship etc.) in the organisation sponsoring or funding the research that may give rise to a possible conflict of interest?

☐ Yes  ☑ No

If Yes, give details:

11. Signatures of applicant(s)

[Signature]

.................Chris DICKINSON.................  ....08/03/2012.............
Signed Date

[Signature]

............... ALI MAZYED AL SHAGHTHRAH................. ....08/03/2012...........
Signed Date

12 Signature by or on behalf of the Head of School

The Committee expects each School to have a pre-screening process for all applications for an ethical opinion on research projects. The purpose of this pre-screening is to ensure that projects are scientifically sound, have been assessed to see if they need ethics approval and, if so, go to the relevant ethics committee. It is not to undertake ethical review itself, which must be undertaken by a formal research ethics committee.

The form must therefore be counter-signed by or on behalf of the Head of School to
signify that this pre-screening process has been undertaken

I approve the submission of this application

---------------------------------------------------------------------------------

Signed by or on behalf of the Head of School       Date:
The effectiveness of optical aids for tunnel vision field

Participant Information Sheet

You are being invited to take part in a research study as part of a student project for a postgraduate degree in Optometry. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

Who will conduct the research?

The research will be conducted by Mr. Ali Alshaghtrah who is a collaborative investigator. The research will be supervised by Professor Christine Dickinson.

What is the aim of the research?

The main objective of the study is to develop a new vision test to be used in the clinic to measure the effectiveness of optical aids in allowing detection of objects in the non-seeing area of the visual field. Several experiments over one to three visits will be carried out to (1) develop a new test of peripheral vision, and then (2) use this test to measure the effectiveness of optical aids to help patients with visual field loss to verify its validity and sensitivity. The method that is proposed here is not a possible treatment of the disease and will not help in restoring the vision, although it could help the clinician to advice the
patient in the most appropriate way to use their vision, and whether optical aids may be worthwhile in their particular case.

**Why have I been chosen?**

This method will be tested by examining adults with normal vision or with a visual field defect caused by retinitis pigmentosa, choroideraemia, Usher's syndrome and Homonymous hemianopsia which has already been identified and diagnosed using established visual field plot. You are being asked to take part because you fall into one of these groups.

**What would I be asked to do if I took part?**

The assessment will first involve pre-assessment optometric tests which will include measuring how well you see with your ordinary spectacles and/or contact lens (visual acuity), a visual field test, and low contrast object detection test. Secondly, you will be asked to search for a black and white square(s) within a gray background on a projector chart with and without various optical aids. If you have normal vision, you will be asked to wear a simulator lens to simulate the visual field defect. Thirdly, if you have retinitis pigmentosa, choroideraemia, and Usher's syndrome we will ask you to answer a questionnaire directed to mobility activities. We will also ask you to walk in an indoor environment at our lab in order to assess your mobility performance. In this task you will be asked to walk while noting the presence of various objects and obstacles in your path.

In general, these activities will be arranged over one to three visits (each lasting form 30 minutes to 3 hours) at a time that suits you.
What happens to the data collected?

The data collected will be used to determine the ability of the proposed clinical measure to evaluate the participant’s awareness ability. The outcome will confirm whether the measure might be a suitable test of evaluating the effectiveness of optical aids for subject with visual field loss or not.

How is confidentiality maintained?

All information collected for this study will be managed in accordance with the Data Protection Act 1998. All data will be coded and anonymous so it is not identified with a particular person. Names, addresses and contact details will only be used to arrange visits and follow-up.

What are the risks?

There are no major risks by performing either the visual search task; or in the walking on an indoor mobility path: any obstacles will be made from soft cardboard in this study. You will be able to withdraw from the study, or from individual experiments, at any time without giving a reason.

What are the benefits?

There are no direct benefits to taking part in the study. It is hoped these measurements will further knowledge on the use of optical aids designed to improve mobility in a population with visual field loss.
What if I decide not to participate?

It is entirely up to you to decide. Those who decide not to participate will not be asked for a reason. You can withdraw from the study at any time without explanation. Neither your GP nor your optometrist will be informed of your participation in this study.

What is the duration of the research?

Initially, you will be contacted to arrange for a convenient time for the first two visits that it suits you. If you have tunnel vision and are eligible for the second part of the study, you will then be asked if you wish to arrange one further visit. You will have the right to decide whether to participate or not.

Will I be paid for participating?

In detail, £15 to cover expenses will be paid for each visit to participants of the healthy volunteer group and £25 per visit (because the visits will be slightly longer and involve more tests) for the participants with visual field loss in addition to your travel expenses if you are coming from outside Manchester.

Where will the research be conducted?

Vision Centre, Carys Bannister Building, Dover Street, University of Manchester, M13 9PL.

Will the outcomes of the research be published?

The findings will be published in a peer reviewed scientific journal, conference presentation, and thesis.
Criminal Records Check (if applicable)

The researchers have undergone a satisfactory criminal records check.

Contact for further information

If you have a concern about any aspect of this study, please speak with the researchers (contact details are given below) who will do their best to answer your questions

Professor Christine Dickinson       Professor of Clinical Optometry

Ali M. Alshaghthrah       Postgraduate research student

Faculty of Life Sciences, Carys Bannister building

University of Manchester,

Manchester M13 9PL

E-mail:

chris.dickinson@manchester.ac.uk

Ali.Alshaghthrah@postgrad.manchester.ac.uk

Mobile Phone: +44 (0)7570366755

If you remain unhappy and wish to complain formally please contact the Head of the Research Office, Christie Building, University of Manchester, Oxford Road, Manchester, M13 9PL.
### Consent Form

A study to develop a new clinical measure to evaluate the visual field awareness in a tunnel vision population.

**Name of Researchers:** Mr. Ali M. Alshaghthrah and Prof. Christine Dickinson

Please read the following and initial each box:

<table>
<thead>
<tr>
<th>I confirm that I have read and understood the invitation and information letter for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected.</td>
<td></td>
</tr>
<tr>
<td>I understand that this study is the purpose of research and not for treatment of any visual conditions that I may have</td>
<td></td>
</tr>
<tr>
<td>I understand that sections of my optometric notes may be looked at by qualified optometrists involved with the research where it is relevant to my taking part. I give permission for these individuals to have access to my records.</td>
<td></td>
</tr>
<tr>
<td>I have been informed that the confidentiality of the information I provide will be safeguarded.</td>
<td></td>
</tr>
<tr>
<td>I agree to take part in the above study.</td>
<td></td>
</tr>
</tbody>
</table>
Instructions for the AVA Test

The participant was asked to sit at 1.20 metres from the projector screen and identify a black and white square which will be presented in 32 different locations on the background. A demo trial will be presented which will show the participant what s/he will see throughout the awareness test and what we are expecting from him/her to report to us.

The instruction was: Your head and "eye movements" are totally allowed (although you must not look outside the simulator (for SIPs)). You will be asked to identify a central target (red or blue cross at the centre of the background) and search for and locate a black and white square, which could be anywhere within the background. After the target is noticed you must immediately press the button. Thereafter a break slide will be presented were you will be asked to give your response about the colour of the central cross (or direction) and the target location in relation to the clock positions (12 o’clock to 10.30...
o’clock) and their distance from the centre (i.e., positions 1 to four). The same procedure will be repeated for the next 32 slides.

**Instruction for the Mobility Course**

You will be wearing your normal refractive correction (in the trial frame for SIP).

**In the first part:** you will be asked to walk for from one point to another in a straight-line at your normal pace (or speed), and there will not be any obstacles obstructing your path. You should not worry about the simulator you are wearing and walk at your normal "everyday" speed.

**In the second part:** you will walk the indoor corridor (twice), but obstacles will be randomly distributed and will vary in size, height, contrast and some of them will be hanging from the ceiling. The obstacles are made from cardboard; therefore don’t worry if you contact any one of them. You should navigate your way through the obstacles until reaching the end of the path (the corridor door), and then stop until I ask you to come back (you should not look back at the hallway until I ask you to do so). If you contact any one of them don’t be shocked and try to carry on as soon as possible.

You will be wearing your normal refractive correction and the optical aid fitted over them (in the second visit for TVPs).
Independent mobility questionnaire (for TVPs only):

**APPENDIX. Independent Mobility Questionnaire**

Part 1

Name: ___________________  Date: ___________________  D.O.B.: ___________________

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

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking in familiar areas</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Walking in unfamiliar areas</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Moving about in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Home</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Work</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Classroom</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Stores</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Outdoors</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Moving about in crowded situations</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Walking at night</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Using public transportation</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Detecting ascending stairwells</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Detecting descending stairwells</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

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 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  

**Part 2**

Other health problems that contribute to limitations in walking around: 

Are you currently on any medication?  ____ Yes  ____ No

If yes, please list: 

Have you fallen in the last year? (By “fallen,” I mean unintentionally come to rest on the ground or at some lower level.)  ____ Yes  ____ No  If so, approximately how many times?  ____ 

Have you had a fear of falling in the last year? (By this I mean you have ever been anxious or worried about falling or been aware of being frightened of falling? This may or may not be associated with a feeling of unsteadiness.)  ____ Yes  ____ No

Do you limit travel by yourself due to your vision loss?  ____ Yes  ____ No

How often do you ask someone to accompany you when you leave your house?  ____ Always  ____ Usually  ____ Sometimes  ____ Never

Are you satisfied with your present level of travel?  ____ Yes  ____ No

Have you ever had any kind of training to help you move around better (“mobility training”)?  ____ Yes  ____ No

If “no”, the main reason is because:  ____ 

It costs too much  ____

I don’t think I need it  ____

Nobody told me training was available  ____

Other  ____

Do you use a mobility aid (e.g., guide dog, cane, sighted companion)?  ____ Yes  ____ No

If yes, in what situations?:

____ Outdoors

____ Indoor, unfamiliar areas

____ Other

Do you believe that your ability to travel on foot by yourself is less than that of people with normal vision?  ____ Yes  ____ No

Do you wear glasses/sunshades to control illumination?  ____ Yes  ____ No

If yes, in which situations?:

____ Outdoor, daylight

____ Outdoor, dusk/night

____ Indoor, brightly lit areas

Which type/color glasses do you use?  ____
Low Vision Quality of Life Questionnaire (LVQOL) for TVPS:

<table>
<thead>
<tr>
<th>Distance Vision, Mobility and Lighting</th>
<th>None</th>
<th>Moderate</th>
<th>Great</th>
<th>x</th>
<th>n/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>With your vision in general</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>With your eyes getting tired (e.g. only being able to do a task for a short period of time)</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>With your vision at night inside the house</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Getting the right amount of light to be able to see</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>With glare (e.g. dazzled by car lights or the sun)</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Seeing street signs</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Seeing the television (appreciating the pictures)</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Seeing moving objects (e.g. cars on the road)</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>With judging the depth or distance of items (e.g. reaching for a glass)</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Seeing steps or curbs</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Getting around outdoors (e.g. on uneven pavements) because of your vision</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Crossing a road with traffic because of your vision</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Adjustment</th>
<th>No</th>
<th>Moderately</th>
<th>Great</th>
<th>x</th>
<th>n/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unhappy at your situation in life</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Frustrated at not being able to do certain tasks</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Restricted in visiting friends or family</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reading and Fine Work</th>
<th>Well</th>
<th>Poorly</th>
<th>Not explained</th>
</tr>
</thead>
<tbody>
<tr>
<td>How well has your eye condition been explained to you</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reading and Fine Work</th>
<th>None</th>
<th>Moderate</th>
<th>Great</th>
<th>x</th>
<th>n/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading large print (e.g. newspaper headlines)</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Reading newspaper text and books</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Reading labels (e.g. on medicine bottles)</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Reading your letters and mail</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Having problems using tools (e.g. threading a needle or cutting)</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activities of Daily Living</th>
<th>None</th>
<th>Moderate</th>
<th>Great</th>
<th>x</th>
<th>n/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finding out the time for yourself</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Writing (e.g. cheques or cards)</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Reading your own hand writing</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>With your every day activities (e.g. house-hold chores)</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Appendix Two
The Visual Detection Distance

The VDD has been used in previous studies to potentially provide additional information about the participant's performance, i.e. their orientation ability (Rich and Ludt, 2003, Leat and Lovie-Kitchin, 2006, Leat and Lovie-Kitchin, 2008). In these studies obstacles were placed on the ground and the subjects were asked to walk until they detected one of the obstacles and then the distance from the subject to the obstacle was measured. However, it appeared that the method that had been used in these studies to assess the VDD may not directly assess travel safety but was an assessment of the participants' VA. For example, placing a chair at 10 metres from the observer and detecting it from that distance may not indicate that the observer would be a safer traveller but could indicate that the observer had the appropriate vision for this task. In this study a new approach was developed to assess VDD, by attaching a piece of card to the wall and asking the participants to look for it while walking down the corridor. The hypothesis was that giving the participants this task would encourage them to scan the environment, which would correlate with the participant's travel safety. The participants were asked to walk through the corridor while scanning for the cards and once they first noticed one of the cards they should stop walking, verbally notify the experimenter, and the distance from the participant to the card was measured.

This part was conducted in a different corridor from the obstacle course, with the same characteristics of length, width and illumination (the mean illuminance was 430 Lux, as measured at 1 metre from the ground). Four cardboard charts (30cm wide x 25cm high) were attached to the walls, on each sides, at different parts of the corridor starting at 2
metres from the start. The position of the cards was randomly changed with each simulator (from 20° to 5°). The cards were black and the wall colour was white, which gave a good contrast level. This measure will be validated by correlating the VDD scores with the FoV. If there are evidences support the validity of this measure, then this measure will be used in the main study and then used in validating the AVA test by correlating VDD with the AVA test scores.

Materials and Methods

Five out of the ten participants that were recruited in the study in Chapter 6 were tested by measuring VDD. The participants’ visual function had been assessed using the same test used in the main study. The VF test was done for every participant, with each simulator, before doing the mobility course. The VF was measured using the Bjerrum screen and the method used to calculated the VF size was described earlier (Chapter 5, section 5.4.2). All participants satisfied the inclusion criteria (Chapter 5, section 5.3.1). The habitual correction was used for all participants (if they had one).

Result

The participants' VA in the RE, without the simulators, was \(-0.01 \pm 0.10\) logMAR (Mean ± SD); (ranging from -0.20 to 0.00). The CS in the RE was \(1.70 \pm 0.10\) log CS (ranging from 1.65 to 1.75 log CS).

The VF defects were simulated for all participants. The means ± SD of the simulated FoV for the four simulators of the 5 participants were \(19° \pm 1°\), range \(18°\) to \(20°\); \(14° \pm 0.75°\), range \(14°\) to \(15°\); \(9° \pm 1°\), range \(9°\) to \(10°\); \(5° \pm 0.50°\), range \(4°\) to \(6°\); respectively.
All the data collected from the mobility course were included in the analysis. The Kolmogorov-Smirnov test showed that the data was normally distributed ($p > 0.05$), therefore parametric tests were used.

The VDD scores appear to increase as the FoV decreases in the first three SIPs groups. However, the VDD was at its lowest distance with SIPs 5° (see Apx 2. Table1 below). The VDD in the SIPs 20° was 6.15 ± 3.40 metres (Means ± SD); the SIPs 15° 7.40±3.50 metres; the SIPs 10° 8.70±2.95 metres and the SIPs 5° 5.70±2.60 metres. No significant relationship was found between the FoV and VDD, $r = 0.01$, $p = 0.94$.

**Discussion**

The VDD was found to be unrelated to FoV. Further, the participants were asked to walk down the corridor while looking for the chart attached to the wall. However, from our observation of the five participants, it was noticed that they did not walk down the corridor but instead walked for a couple of metres, spotting all the charts attached to the wall. Further, we faced difficulties in scoring the VDD in cases of the participants failing to detect one or more of the charts. In other words, what would be the best way to account for the participants who failed to detect one or more of the charts? For example, if we were to consider all the missing charts as missing scores, this would mean that we would be considering the good scores only, which would provide misleading information. On the other hand, if we wanted to add few metres to the VDD scores for every missing chart, we would not know the appropriate distance to add on. Additionally, even though we changed the positions of the charts for every participant for every FoV size, it was noticed that the participants' scores improved as the FoV size decreased. These
observations indicated that the VDD did not satisfy our objectives, i.e. it was not found to be sensitive or to provide enough additional information about the participants' travel safety. Therefore, it was decided that the VDD score should not be used in the main study.
The difference in the mobility courses between both buildings

A planned change of building took place after 19 participants had been recruited and had made two visits. An experiment was conducted to compare the participants' performance over both courses and to measure the equivalence of the courses. The same layout of the old building was used in the new building. All 19 participants were contacted, but only six of them had the time to attend; SIPs 5, 6, 8, 16, 17, and 19 participated in this experiment. The mobility scores that were collected from their second visit were used to take into account any learning effect compared to their scores on the third visit.

Methods and Materials

All the methods and materials used in the main study were used here.

Results

The data collected from both mobility courses were tested for normality. The test showed that data were normally distributed; Kolmogorov-Smirnov: $p > 0.05$. Hence, parametric tests were used where appropriate.

The Mobility Course Scores

The changes were by small percentages in PPWS where the participants were slower in the new building in SIPs 20°, 15° and 10°, and were faster in SIPs 5°. In the collision scores, there was almost no change in scores in SIPs 20° and 15°, more incidences in SIPs 10°, and fewer collisions in SIPs 5°.
Table 1. The mean ± SD for the PPWS, and collisions scores on the two visits

<table>
<thead>
<tr>
<th>Angle</th>
<th>Old building PPWS Mean ± SD</th>
<th>New building PPWS Mean ± SD</th>
<th>Old building Collisions Mean ± SD</th>
<th>New building Collisions Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>20°</td>
<td>44.50 ± 14.50</td>
<td>37.00 ± 5.75</td>
<td>0.50 ± 0.75</td>
<td>0.75 ± 0.50</td>
</tr>
<tr>
<td>15°</td>
<td>35.25 ± 15.00</td>
<td>31.50 ± 7.50</td>
<td>1.00 ± 0.50</td>
<td>1.00 ± 1.00</td>
</tr>
<tr>
<td>10°</td>
<td>30.75 ± 8.75</td>
<td>29.00 ± 7.25</td>
<td>0.75 ± 0.50</td>
<td>1.25 ± 0.75</td>
</tr>
<tr>
<td>5°</td>
<td>22.00 ± 6.00</td>
<td>24.00 ± 5.25</td>
<td>2.75 ± 1.25</td>
<td>2.00 ± 0.50</td>
</tr>
</tbody>
</table>

A two-way MANOVA was conducted to explore the differences in participants’ performance between both courses. There was no statistically significant difference between both courses on the combined mobility scores (PPWS, Collisions), $F(2, 42) = 0.50, p = 0.61$; Wilks’ Lambda = 0.98. When the results for both scores were considered separately, both scores did not reach statistical significance. In detail, the PPWS, $F(1, 43) = 1.03, p = 0.32$; the collisions $F(1, 43) = 0.01, p = 0.93$. The calculated effect size was very small, only 2% of the variance in PPWS scores and less than 1% of the variance in collisions could explained by the change in the mobility course.

**Discussion**

There was a minor variation in mobility scores, however, this variation was not found to be statistically significant. This finding provides evidence that the mobility course design that was used here could be replicated in any other place as long as the main characteristics of the course are maintained. To conclude, the same course was used in the new building and the data collected from the old and new buildings were pooled and analysed as a whole.
Appendix Three
Projector Luminance Stability

Hitachi CP-X325 multimedia mobile projector

A projector with a short focal length was used (CP-AW100N, Hitachi, UK) in order to produce the background and stimulus for the AVA test. The luminance of background and target were both specified for the test, so it was important to determine that the luminance provided by the projector was stable.

Method

Once the projector was switched on, the luminance stability was tested when the luminance reading was stable to find out the time needed for the projector to reach its full functioning. The background was a blank white field. The measurement was taken repeatedly once the projector was switched on and the intervals between measurements were as short as possible to gather as many readings as feasible. Additionally, the luminance was measured every five minutes over a 60 minute period, five minutes after the projector had been switched on. This was the maximum time that the AVA test would be conducted for. Readings were taken from one central position while the projected image was a uniform white background. Finally, the luminance stability across the area of the field over 60 minutes was tested, in order to investigate if the projector could provide a stable and uniform luminance while conducting the AVA test. The display was divided into four quadrants: upper right and left quadrants and lower right and left quadrants. In each quadrant a position was chosen and the luminance was tested every five minutes.
Results

Fifteen readings were taken within the first minute. The time taken to reach the plateau luminance level was almost one minute. Once the projector was switched on the luminance rapidly increased from 5 cd/m² to 68 cd/m² in steps of almost 5 cd/m² (Figure 1).

Apx 3. Figure 1. Fifteen consecutive readings show the increase in luminance within the first minute after switching the projector on.

The luminance was stable over time, with a mean of 67.25 ± 0.79 cd/m². This outcome indicated that the projector could produce a stable luminance after a few minutes of being switched on (Figure 2).
Apx 3. Figure 2. The white background luminance measured at five minutes intervals in one central position on the projector screen over a period of 60 minutes.

The luminance was found to be generally stable in the four quadrants. The mean luminance in the upper right and left quadrants was approximately 66.00 ± 2.00 cd/m², and in the lower right and left quadrants about 67.00 ± 1.50 cd/m². This result indicates that the projector is able to provide a uniform luminance across the area of the field over 60 minutes.

In conclusion, the projector was found to provide a stable and uniform luminance level over the time needed to perform the AVA test.
Tri-field Prism Fitting Procedure

The Tri-field prism fitting procedure was based on the recommendation in Woods et al. (2010a). A conventional single vision (or plano) lens was placed over the eye with better VA or with the bigger VF size. The prism lens was fitted over the other eye. The prism lens included any required distance optical correction (if any), with both prism apices splitting the pupil. The prism powers needed to be large enough in order to avoid diplopia. Diplopia is expected to take place if the prism power causes a shift (in degrees) that is smaller than the retained VF (in diameter). Once the VF is separated, fusion is eliminated and the eyes are expected to take up the phoria position with the Tri-field prism. Phoria measurements were taken at two intermediate distances (3 and 15 feet) and were used to adjust the prism powers to account for the effect of phoria. These particular distances were suggested by Woods et al. to be the two distances that were considered to be at the limits of the range of obstacle distances expected to be usefully detected with the Tri-field prism.

The Maddox rod procedure was used to test the phoria. In detail, the Maddox rod was placed horizontally in a trial frame and an ocular transilluminator was focused on the midline of the participant's face. It was explained to the participant that s/he would see a red line and white dot and they were asked if the dot was superimposed on the red line. If the participant's answer was yes, no deviation was present. If the participant's answer was no, a prism correction was used. The prism was placed, in the trial frame, in the proper orientation (BI prism for Exo-deviation and BO prism for Eso-deviation), and was increased until the dot was superimposed on the line.
The procedure used to calculate the prism power was the following: for example, if the participant was wearing the prism over the RE, the temporal prism power had to be large enough to shift the right temporal (RT) field of the RE to the edge of the left temporal (LT) field of the LE (Figure 1). So if the RT field was equal to 5° and the LT field equal to 10°, the total shift needed was 15° which was equivalent to 25Δ (1Δ ≈ 0.6°). However, this amount did not take into account any deviation present. If the participant had 3Δ exophoria at the two distances, the prism power was reduced by the same amount. This meant that the prism power was 22Δ and so 2Δ was added to the prism power to ensure that we would avoid the diplopia. Finally, as we used the Fresnel prism, the prism power was rounded up to the nearest power, thus the power used in this case was 25°.

Apx 3. Figure 3. An example of the VF size for each side in each eye. RE refer to right eye, LE refer to left eye, RT refer to the right temporal side, RN refer to the right nasal side, LN left nasal side and LT left temporal side.

**The VF Measuring Procedure**

The extent of the VF with the Tri-field was assessed using Bjerrum VF test. The definitions of the VF extent used in this project were based on the definitions suggested by Woods et al. (2010a). The monocular VF extent was defined as the distance between
temporal and nasal edges. The binocular VF without the prism was defined as the "width of the horizontal extent that would be covered by either eye" (Woods et al., 2010a).

With the Tri-field prism, the VF was measured in the following steps (some of these steps were described by Woods et al. (2010a)):

The test was explained to the participant thoroughly, emphasizing the necessity for full cooperation and the need to verbally report as soon as the white stimulus was noticed (5mm in size).

The participant was seated and a chin and forehead rest was used to place the participant at a distance of 1 metre from the Bjerrum screen.

The participant was asked to fixate on a central dot with the non-prism eye (left eye in this example) and was asked to move the head slightly to the right. That change in head position brought the nasal prism in front of the RE. The VF of the LE was measured under this condition, then the RE VF covering the field area to the left of the fixation target was measured.

The participant was then asked to tilt the head to the left, to bring the temporal prism in front of the RE. The field area to the right of the fixation target was then measured.

The target was moved at a steady rate, at 2 deg s⁻¹, from 30° in the periphery towards the centre. The VF expansion was determined based on the definition proposed by Woods and colleagues (2010a), which is "the distance between the leftmost edge of the left expanded area and the rightmost edge of the right expanded area".
This procedure faced challenges in the third and fourth steps with the first two participants as there was confusion in determining the edge of the expanded field area. This may have been because the participant was viewing through the non-prism eye. Therefore, a change in the procedure was introduced in the third and fourth step, which was to patch the participant’s LE.

The participant was asked to move the head slightly to the right and fixate at the central target, thus bringing the nasal prism in front of the RE. The VF of the RE covering the field area to the left of the fixation target was measured.

The participant was then asked to tilt the head to the left, to bring the temporal prism in front of the RE. The field area to the right of the fixation target was then measured. The target was moved at a steady rate of at 2 deg s\(^{-1}\) from 30° in the periphery towards the centre.

The VF of the LE, the expanded right field area and the expanded left field area was then plotted in a VF plot form. As the participant was fixating at the central target the displacement of the VF was minimal and adjustments of the VF lateral edge position of the expanded field area were needed. The lateral edges of the left and right field area were moved to the left and right respectively, in accordance with the prism power used. For instance, if 35Δ was used, the nasal and temporal edges of the left field area were moved to the left by 21° (1Δ ≈ 0.6°); the same procedure was done for the right field area. The three field areas were then plotted in the VF plot form.

The VF expansion was determined based on the definition proposed by Woods and
colleagues (2010a), which is “the distance between the leftmost edge of the left expanded area and the rightmost edge of the right expanded area”.
Hemianopic Patient No. 1

ID: Esterman Binocular

Fixation Monitor: OFF
Fixation Target: Central
Fixation Losses: 0/0
False POS Errors: 0/13
False NEG Errors: 0/13
Test Duration: 06:04
Stimulus Intensity: 10 dB

Stimulus: III. White
Background: 31.5 ASB
Strategy: Two Zone
Test Mode: Single Intensity

Pupil Diameter: [Data]
Visual Acuity: [Data]
RX: DS DC X

Date: 26-03-2012
Time: 09:49
Age: 67

The Vision Centre
The University of Manchester
PO Box 88 Manchester
M60 1QD

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HFA II 720-3592-14.2.1/14.2.
Hemianopic Patient No. 2

Esterman Binocular

Fixation Monitor: OFF
Fixation Target: Central
Fixation Losses: 0/0
False POS Errors: 0/12
False NEG Errors: 1/11
Test Duration: 05:56
Stimulus Intensity: 10 dB

Stimulus: III, White
Background: 31.5 ASB
Strategy: Two Zone
Test Mode: Single Intensity

Pupil Diameter:
Visual Acuity:
RX: DS DC X

Date: 08-11-2010
Time: 13:41
Age: 70

The University of Manchester
Faculty of Life Sciences

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HFA II 720-5035-4.2/4.2