Mobility performance with retinitis pigmentosa

Purpose: Reduced mobility can have a serious impact on quality of life. Though previous studies have demonstrated that some vision measures relate to the mobility of subjects with simulated and true low vision, the relationship between residual vision and mobility is not clear. We investigated the relationship between clinical vision measures and mobility performance under different illumination levels for subjects with retinitis pigmentosa (RP).

Methods: Binocular visual acuities, letter contrast sensitivities and static central threshold visual fields were measured on 10 subjects with RP and nine age-matched control subjects. Mobility performance was measured on an indoor mobility course at high and low illuminances and was assessed by percentage preferred walking speed (PPWS) and number of errors.

Results: The RP group showed significantly reduced PPWS and greater numbers of errors than the control group. The reduction in illumination resulted in significantly worse error and PPWS scores. Unlike the control group, the presence of a glare source did not reduce the PPWS of the RP group under high illumination. Multiple regression analyses showed that the average visual field extent was the most significant predictor of mobility; letter contrast sensitivity and visual acuity added to the regression models for the low illumination measures to account for up to 75 per cent of the variation in mobility performance.

Conclusions: People with RP have worse mobility than people with normal vision, more so under reduced illumination levels. Visual field extent was the strongest predictor of mobility performance.

Key words: mobility, retinitis pigmentosa
Mobility with RP Black et al

different mobility problems. While numerous studies have assessed the mobility of the totally blind, relatively few have addressed the mobility needs of those with low vision and even fewer studies have concentrated on particular low vision groups.

Retinitis pigmentosa is a slow dystrophic disease which leads to poor night vision and abnormal visual adaptation due to loss of rod and cone function, gradual constriction of the peripheral visual field and reduced peripheral awareness, reduction in central visual field size and progressive loss of colour discrimination. Advanced stages of the disease may result in a reduction of visual acuity due to either the presence of posterior sub-capsular cataracts, foveal lesions or progression of the disease centrally.3 Given these problems, independent travel can be particularly stressful and difficult for people with RP. Commonly reported mobility problems of people with RP have included tripping and falling, difficulty with lighting levels and bumping into people and objects.4,6

Mobility assessment

Previous research of low vision mobility performance is diverse. Variations exist in the types of mobility courses, the mobility performance scoring techniques and the types of subjects tested. As a consequence of this lack of uniformity, results between mobility studies are difficult to compare.

MOBILITY SCORING

Scoring of mobility performance should provide an objective and quantitative assessment of a person's independent travel. To date, assessment of mobility performance has been based on the measurement of speed/time and/or error scores.

'Speed/time' scores assess the efficiency of independent travel. The score is related to the confidence of the subject and the degree of 'stress' placed on the subject within the environment; those with low vision will naturally slow down in more complex or unfamiliar areas. The reliability of speed or time scores is improved by expressing a subject's walking speed as a percentage of preferred walking speed, which is a separate measure of their walking speed along an unobstructed pathway. The percentage of preferred walking speed (PPWS) is an objective measure of mobility performance which allows more valid inter-subject comparisons to be made, by accounting for variations in ages and the physical attributes of the subjects.4 Clark-Carter and colleagues' claimed that the use of the PPWS allows smaller subject samples to be used in experiments, given the reduction in inter-subject variation.

The 'number of errors' made along a mobility course is an indicator of travel 'safety', as the occurrence of errors, such as contacts with obstacles, is considered 'unsafe' mobility. A variety of error scoring techniques have been employed by previous studies, including contact with obstacles,2,6 strays from the marked pathway,11 combinations of both obstacle contacts and path strays3 and 'mobility incidents' consisting of high stepping, missed curbs, loss of balance, obstacle contact, shuffling, stopping, examiner intervention, veering and path strays.4 Marron and Bailey4 weighted the error scores according to the time taken to recover from disorientation following contact with an obstacle. Most studies have used the total number of errors in the analysis of data. Marron and Bailey4 formulated an index of performance $[log((100)/(1+\text{number of errors}))]$ which they claimed improved the error weighting with higher scores indicating better mobility performance.

MOBILITY COURSES

Both indoor and outdoor courses have been used to assess mobility performance. All courses used in previous studies have been unique and have varied in their task complexity, due to different course designs and obstacles, which consequently makes comparison between studies difficult. Indoor courses, used by Brown and co-workers,* Lovie-Kitchin and colleagues3 and Alfano and Michel11 were simple, safe, convenient and allowed control over variables such as illumination. Outdoor courses, as used by Clark-Carter and colleagues and Haymes and colleagues8,13 gave excellent real-world simulations because of the wide variations in contrasts, spatial frequencies and natural terrain, which ultimately provided greater challenges to the low vision subjects. Unfortunately, the variables studied on outdoor courses are inevitably diluted by the extraneous, uncontrolled and unmeasurable variables.14 Marron and Bailey,4 Pelli10 and Long and colleagues' used indoor and outdoor courses which enabled more practical assessment of mobility performance, since the reality of an outdoor course was used, along with the controlled environment of an indoor course.

The number of obstacles used within previous mobility courses have varied greatly, ranging from zero to 87. Indoor courses, unlike real-world courses, can include greater numbers of obstacles, which, according to Lovie-Kitchin and colleagues,3 allows a greater range of error scores to represent variations in mobility performance. The types of obstacles used have also varied between studies; Pelli10 used identical vertical poles, Marron and Bailey4 used suspended paper cylinders of varying diameter, while Lovie-Kitchin and colleagues3 used a wide range of foam and cardboard objects of different sizes and contrasts in an attempt to provide a more realistic environment. The positioning of obstacles within the mobility course has ranged from randomly positioned set course designs3 to variable courses, in which obstacles were randomly positioned prior to each test, which allowed retesting to be performed without learning effects.10

SUBJECTS TESTED

Subjects tested in previous studies have differed widely, most being heterogeneous low vision groups1,5,9 or subjects with simulated low vision.8,10,11 Brown and co-workers* and Haymes and colleagues13 used low vision subjects with age-related maculopathy (ARM) and RP respectively. Simulated low vision is often used as it is difficult to find low vision subjects who are affected to the same extent. Although only an approximation of reality, simulated low vision is useful for developing concepts because complex variables can be controlled,* as artificial restrictions produce

Clinical and Experimental Optometry 80.1 January-February 1997
stable and repeatable results,\textsuperscript{10} Even within low vision groups, there is variability induced by subjects with differing levels of prior mobility training or those who may rely on mobility devices. However, as particular ocular conditions affect specific visual functions, only limited information relating to the mobility performance of a person with a particular cause of low vision can be gained from results using simulated or heterogenous low vision groups. For that reason, specific low vision groups should be used if mobility performance is to be predicted for specific conditions.

Mobility and residual vision
The combinations of visual functions which are important to mobility are still not entirely understood. The first order parameters of any optical system, such as the eye, are the field of view, resolution (acuity) and spatial contrast sensitivity.\textsuperscript{10} These three parameters have been the major visual functions examined for their effect on mobility performance. As for the methods of assessing mobility performance, the methods used in previous studies to assess and score residual vision have been diverse.

Visual acuity has been shown to have no significant correlation with mobility performance for heterogenous low vision groups.\textsuperscript{5,8} Pelli\textsuperscript{9} found that mobility performance within a maze and shopping mall for their simulated low vision subjects was severely affected when visual acuity was reduced to 6/600 or worse. Conversely, Brown and co-workers\textsuperscript{8,9} used subjects with ARM and Haymes and colleagues\textsuperscript{8,13} found significant correlations between visual acuity and mobility measures for their homogenous subject groups. Brown and co-workers\textsuperscript{12} used subjects with ARM and Haymes and colleagues used both normally sighted subjects with constant visual field restrictions to simulate RP\textsuperscript{8} and subjects with true RP.\textsuperscript{13}

Contrast sensitivity (CS) is a measure of the ability to detect objects of varying size and contrast. Typically, subjects with low vision have reduced CS across all spatial frequencies, with the peak CS being reduced and displaced towards lower spatial frequencies compared with that of age-matched subjects with normal vision.\textsuperscript{3,15} Measures of edge detection such as the Melbourne Edge Test (MET), are most highly correlated with peak CS.\textsuperscript{16} MET scores reduce as illumination decreases\textsuperscript{*} and are lower among those with low vision.\textsuperscript{11} The high correlation between CS and object detection and recognition\textsuperscript{17} suggests another link with mobility. In an elderly population the frequency of reports of difficulty with mobility tasks has been found to increase as measured CS (Pelli-Robson chart) worsened.\textsuperscript{18} Therefore, reduced CS is expected to reduce mobility performance, because either more errors will be made as obstacles will be harder to detect and/or a slower walking speed will be adopted, because more caution will be taken to avoid these obstacles.

Peak CS has been shown to explain some variability in mobility performance; Marron and Bailey\textsuperscript{9} and Long and co-workers' showed that peak CS accounted for 32 per cent and 14 per cent of variance in mobility performance respectively. The variations in results can be accounted for by the differing courses and differing heterogenous low vision groups. Marron and Bailey\textsuperscript{9} examined the correlations between mobility and all measured spatial frequencies and found the greatest correlation with the peak CS. This was confirmed by Haymes and colleagues\textsuperscript{4} who reported that low contrast visual acuity, which does not measure the peak CS, was not a significant variable, while the data from the Melbourne Edge Test was a significant variable and accounted for 30 per cent of variance in mobility performance of their subjects with simulated RP. These studies suggest that peak CS is more highly correlated with mobility performance than any other CS measures.

Visual field extent has consistently been found to be important in mobility performance. Although results vary, all studies consistently show that the smaller the central visual field, the worse the mobility. Using simulated visual field restriction on normally sighted subjects, Pelli\textsuperscript{9} and Alfano and Michel\textsuperscript{11} found worse mobility performance as the visual field extent was restricted, especially with restriction to less than 14 degrees. This marked constriction before mobility was severely impaired probably reflects their use of normally sighted subjects, the simple course designs and the restriction of visual field without any other visual degradations. Marron and Bailey\textsuperscript{9} and Long and colleagues found that the visual field extent of their heterogenous low vision groups accounted for 30 per cent and 14 per cent of variance in mobility performance respectively. Similarly, Lovie-Ritchin and colleagues\textsuperscript{5} with a heterogenous low vision group and a relatively complex indoor course, reported that up to 70 per cent of the variance in the reduction in mobility performance could be explained by decreasing binocular visual field area. In particular Lovie-Ritchin and colleagues demonstrated that central and lower visual field area were better predictors of mobility performance than other regions of the visual field.

Subjects with RP follow similar trends. Haymes and colleagues,\textsuperscript{11} using an outdoor course, found that visual field accounted for 59 per cent of the variance in mobility performance, with smaller visual field extents correlating with poorer mobility performance. The small variations in results are due to the different mobility measures and the constitution of the low vision groups, along with variations in the visual field assessment methods. Marron and co-workers' tested binocularly a 140-degree field extent with a bowl perimeter, Marron and Bailey\textsuperscript{9} tested the monocular 80-degree field extent on a tangent screen. Lovie-Kitchin and colleagues\textsuperscript{8} used an arc perimeter to measure the binocular visual field and Haymes and colleagues\textsuperscript{13} assessed binocular kinetic fields on a Goldmann perimeter using a large bright target. It is expected that the loss of peripheral visual field for people with RP will result in mobility errors, as obstacles may lie outside of the field of view, and in reduced speed as they may walk with more caution to avoid these obstacles.

The combined effects of visual field and CS on true low vision groups have been shown to account for 39 per cent;\textsuperscript{12,13} 53 per...
cent\(^6\) and 64 per cent\(^15\) of the variance in measured mobility performance, all of which were greater than that explained by either measure alone. This suggests that the combined loss of visual functions, which occur in RP, causes greater reductions in mobility.

Illumination and mobility

Haymes and colleagues\(^2\) argue that the predictive value of clinical visual measures, such as visual acuity, visual fields and CS, are applicable only if the measurements are conducted under the same conditions as the mobility performance. Similarly, Genensky and co-workers\(^5\) believe that traditional measures of visual function are made under conditions inappropriate for prediction of real world visual performance. An anecdotal report, that lower than normal background illumination in a Goldmann perimeter markedly decreases visual fields of subjects with RP\(^9\) supports the suggestion that indoor clinical measures may not predict mobility performance under different illuminations.

The effect of illumination on the visual functioning of the low vision patient can significantly affect mobility performance. Smith and colleagues\(^6\) in a survey of orientation and mobility specialists and people with low vision, found that lighting conditions and adapting to changes in lighting (for example, walking in crowds in dim illumination) emerged as the major mobility problem for those with low vision. According to Genensky and co-workers\(^5\), 80 per cent of low vision patients have serious difficulty adjusting from daylight to dim lighting. The optimal illumination levels for visual performance for people with normal vision range from 100 to 500 lux, whereas the range for the low vision group is from five to 5000 lux, with very narrow individual tolerance ranges for the optimal levels.\(^7\)\(^,\)\(^8\)

As luminance is reduced from 10 cd/m\(^2\) to 0.1 cd/m\(^2\), the CS of people with normal vision decreases by a factor of six over all spatial frequencies but the CS of subjects with RP decreases by a factor of 10 for low spatial frequencies and 20 for high spatial frequencies.\(^5\) The consequence of the reduced CS is that subjects with low vision have a reduced ability to detect objects under low light conditions.\(^9\) Long and colleagues\(^8\) reported that mobility errors increased by a factor of between two and four at low illumination levels, simulated by one per cent transmission UV sunglasses for a heterogeneous low vision group. Similarly, Haymes and colleagues\(^2\) found that mobility performance (PPWS) was reduced with decreasing retinal illumination, for a constant simulated visual field restriction on normally sighted subjects. As the peak CS and visual field extent have been shown to be highly predictive of mobility performance,\(^1\)\(^,\)\(^3\)\(^,\)\(^5\) the reduction in these functions under lower illumination suggests that performance of people with RP would be adversely affected by reduced illumination.

To compare the mobility performance of people with RP measured under different illumination levels with that of people with normal vision, we examined the ability of clinical vision measures to predict the mobility performance of subjects with RP under these different illumination levels. Based on previous research findings, we hypothesised that mobility performance would be reduced for those with RP, compared with age-matched normal controls and would be worse again under reduced illumination; that visual acuity would not be a significant predictor of mobility performance; and that the predictive value of CS and visual field extent would be higher for mobility performance measured under high illumination (similar to that used for these vision measures).

METHODS

Subjects

Two groups of subjects participated in the study, one group with visual impairment due to RP and the other a group of age-matched control subjects with normal vision. All subjects gave informed consent before undertaking the study.

The 10 subjects with RP (four male and six female) were recruited from three sources: The Retinitis Pigmentosa Association of Queensland, the clinical records of the Queensland University of Technology Vision Rehabilitation Centre and the clinical records of private optometric practices. The only criterion for selection was that they had no physical disability, except for the visual disorder, that was likely to impair mobility. No subject had a hearing impairment. Patients with previous mobility training and those who used white canes were included in the study. All subjects with RP had a confirmed diagnosis from an optometrist or ophthalmologist. Direct ophthalmoscopy was performed to assess the extent of retinal and media changes.

Nine age-matched control subjects (seven males and two females) participated, all of whom had corrected binocular visual acuities of 6/6 or better, had normal binocular visual fields, and were screened for pathology with direct ophthalmoscopy. Subjects had no physical disabilities which were likely to impair mobility.

Age was matched for the two groups, with a mean age of 45.2 ± 11 years (range of 29 to 63) for the RP group and 46.8 ± 14 years (range of 28 to 65) for the control group. As this study investigated the visual functioning of subjects under everyday conditions, subjects' habitual spectacle corrections were used for all clinical vision tests and mobility trials.

Vision assessment

VISUAL ACUITY

Binocular visual acuity (with habitual correction) was measured using a high-contrast Bailey-Lovie letter chart and recorded in logMAR units in 0.02 steps according to the scoring scheme of Kitchin and Bailey.\(^2\) Average chart illumination was 500 lux. A score of 3.00 (logMAR) was recorded for one subject for whom we could not measure visual acuity.

CONTRAST SENSITIVITY

Binocular letter CS was measured with the Pelli-Robson chart at three metres. The letter CS would be expected to be correlated most highly with grating CS at three
To increase reliability, each letter read correctly was given a score of 0.05 log CS units and the miscalculation of the letter ‘C’ as an ‘0’ or vice versa was accepted as a correct call. \(^{19,27}\)

Subjects were encouraged to view the chart for at least 20 seconds. Average chart illumination was 500 lux. A score of 0.00 (log CS) was recorded for one subject for whom we could not measure CS.

**Visual Field**

Binocular visual field of each subject was measured using the automated Humphrey field analyser (HFA-model No. 630). The static 30-2 program was used to measure the visual field out to 30 degrees from fixation, with the blind spot fixation monitor disabled to allow assessment of the binocular visual field. Only the central visual field was assessed as Lovie-Kitchin and colleagues\(^3\) found that the central visual field was the most important area for mobility performance. The habitual reading correction was used for visual field measurement and the subject was positioned so that the bridge of the nose was centered with the monitoring telescope of the instrument. Subjects were instructed to fixate the central spot at all times with frequent verbal reminders to maintain fixation given during the test.

Binocular visual fields were measured twice for the RP group. As some of the subjects with RP may not have been experienced in automated static perimetry, only the second visual field results were used for analysis, given the improved reliability shown by repeated testing.\(^{28}\) The control group performed the binocular visual field once (with Fastpac program engaged) to ensure normal binocular central visual fields.

The visual field extents along the eight principal meridians were averaged to give the average visual field extent (degrees). The extent in any one meridian was taken as the midpoint between the last visible point and the point at which there was no measurable sensitivity on the Humphrey field analyser. For example, if a point at 12 degrees from fixation along the vertical midline was detected, but the point at 18 degrees from fixation was not detected (that is sensitivity was measured as less than zero decibel), the vertical visual field extent was recorded as 15 degrees from fixation. Since all control subjects had peripheral visual field extent well beyond the range of the Humphrey field analyser (30 degrees), control subjects were scored as having a visual field extent of 90 degrees.

**Mobility Assessment**

**Preferred Walking Speed (PWS)**

Each subject’s PWS was determined by measuring the time taken to walk an unobstructed level corridor 20 metres long. The subjects were instructed to walk at a normal, comfortable pace along the corridor; those with RP who usually used white canes were not allowed to use them. Two measurements were obtained and the mean time was converted to PWS (metres per second). Previously, Clark-Carter and colleagues’ used a sighted guide technique to determine subjects’ PWS; we did not consider this necessary for our subject group as they were able to navigate this simple routine unassisted.

**Mobility Course**

Mobility was assessed by measuring the time taken and the number of errors made on an indoor course constructed of a marked pathway, 12 metres wide and 57.5 metres long through three rooms (Figure 1). The pathway was marked with cream masking tape on the blue-grey carpet floor. An indoor course was used so that illumination could be controlled.

To create disability glare, Room 2, through which subjects walked in a straight line (Figure 1), contained only a 14 cm, 200-watt spotlight positioned 1.2 metres from the floor and at an angle of 11 degrees to the right of the centre of the entrance doorway, such that it pointed directly at subjects as soon as they opened the door to Room 2. The 55 obstacles in the other two rooms were made of foam rubber, cardboard or polystyrene, all of which varied in size and contrast. They were positioned randomly on the floor, suspended from the roof or protruded onto the pathway from the side. A step and ramp (1.09 metres long, one metre wide, inclined at eight degrees to give a 16 cm high step), covered in grey cloth, was incorporated into the course. Errors in the course were defined as either a contact with obstacles, loss of balance on the step or ramp, or straying from the marked path. Time to travel through each room was measured in seconds with a stop watch.

Prior to entering the mobility course, each subject sat in an adjacent room, set at an equivalent illumination, for a minimum of 10 minutes to ensure adaptation. While in this room, subjects were given instructions for the mobility course. The instructions were to follow the marked path at a comfortable walking pace, to avoid contact with the obstacles, to open the two doors between the rooms and to touch the final door in Room 3, which marked the end of the course. For safety reasons, subjects were informed of the presence of the glare source and the step and ramp. Mobility devices were not permitted to be used on the mobility course.

Each subject walked through the course twice, once under high illumination and once under low illumination (Table 1). The order of the two mobility trials was balanced, with half of each group performing the high illumination trial first and the other half performing the low illumination trial first, to average out the learning effects between the two illuminations.

The times to walk each room and the total time for the course were converted into metres/second (m/s), and expressed as a percentage of the preferred walking speed (PPWS). For example, if a subject with a PWS of 2.0 m/s walked Room 1 at 1.5 m/s, the PPWS was 75; that is, that person walked at 75 per cent of his/her normal unobstructed walking speed within Room 1. The total number of errors, summed for all three rooms, for each mobility trial through the course was recorded. Since the number of errors is a measure of a relatively rare event, the frequency distributions may not be normal. Hence, the error score was calculated as follows:

\[
\text{error score} = \log_{10} \left( \frac{20}{1 + \text{number of errors}} \right) 
\]
The number 20 was arbitrarily chosen based on the maximum recorded number of errors (18). Error score in our study ranged approximately from 0 to 1.3, with a higher score indicating better performance (fewer errors). This is similar to the measure employed by Marron and Bailey.8

Data analysis
In summary, the following data were obtained for each subject: three clinical vision measures—visual acuity (logMAR), log CS and average visual field extent (degrees)—and two mobility measures—PPWS and error score—for both high and low illumination trials. The distributions of data for each of the subject groups were not significantly different from normal distributions (Kolmogorov-Smirnov test, p > 0.10) except for the error score at high luminance for control subjects (p = 0.04). Despite this one deviation from normality, parametric statistics were used for analyses.

Repeated measures analyses of variance (ANOVA) were used to examine the differences in mobility measures between the RP and control groups under the high and low illuminances. Order was included as a between-subjects factor in each repeated measures ANOVA, to remove the learning effects between the two trials. Similarly, repeated measures ANOVA were performed for the PPWS scores in each room between the two illuminances and between the groups. Post-hoc paired student t tests were used to determine which rooms, if any, showed significantly different PPWS scores.

The relationships between the mobility scores and the vision measures of the RP group were examined using correlations and multiple regression analyses. Stepwise multiple regression analysis, which excludes statistically redundant terms, was used to determine which clinical vision measure(s), if any, best predicted mobility performance. Multiple correlation coefficients ($r^2$) were adjusted for the number of subjects and the number of terms in each equation.

RESULTS

Mobility performance
The mean results for each mobility measure for the RP and control groups are listed in Table 2. There is more variability in the RP group data than in the control group data, which presumably represents individual differences in the disease state.

The subjects with RP were significantly slower and made significantly more errors (smaller error score) than did the control subjects, irrespective of the order or illumination of the trials (repeated measures ANOVA, $p = 0.002$, $p < 0.001$ respectively). The RP group had a slightly reduced PPWS under the low illumination compared with the high illumination ($p = 0.03$) and the error score was worse under low illumination than under high illumination.
Table 1. Mean and range of illuminances in each room of the mobility course.

<table>
<thead>
<tr>
<th>Illumination</th>
<th>Room 1</th>
<th>Room 2</th>
<th>Room 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>25 lux (range 15-27)</td>
<td>26 lux (range 15-41)</td>
<td>28 lux (range 24-30)</td>
</tr>
<tr>
<td>High</td>
<td>500 lux (range 310-570)</td>
<td>360 lux (range 300-400)</td>
<td>480 lux (range 440-530)</td>
</tr>
</tbody>
</table>

Table 2. Mean and standard deviation of the mobility measures for the RP and control subjects under the high and low illuminations.

<table>
<thead>
<tr>
<th>Mobility measures</th>
<th>RP group High illumination</th>
<th>RP group Low illumination</th>
<th>Control group High illumination</th>
<th>Control group Low illumination</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPWS (%)</td>
<td>47 ± 16</td>
<td>42 ± 15</td>
<td>66 ± 9</td>
<td>65 ± 10</td>
</tr>
<tr>
<td>Number of errors</td>
<td>5.8 ± 6.0</td>
<td>8.8 ± 6.3</td>
<td>0.2 ± 0.4</td>
<td>0.8 ± 1.0</td>
</tr>
<tr>
<td>Error score</td>
<td>0.63 ± 0.41</td>
<td>0.44 ± 0.42</td>
<td>1.23 ± 0.13</td>
<td>1.17 ± 0.22</td>
</tr>
<tr>
<td>log10(error/(1+errors))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. PPWS and standard deviation for RP and control subjects for each room. (*significant difference between high and low illumination trials, p < 0.05)

<table>
<thead>
<tr>
<th>Illumination</th>
<th>RP group Room 1</th>
<th>Room 2*</th>
<th>Room 3</th>
<th>Control group Room 1</th>
<th>Room 2</th>
<th>Room 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>48 ± 17</td>
<td>45 ± 14</td>
<td>46 ± 16</td>
<td>69 ± 9</td>
<td>65 ± 11</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>44 ± 16</td>
<td>33 ± 13</td>
<td>42 ± 15</td>
<td>70 ± 12</td>
<td>65 ± 9</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Mean age and clinical vision measures for the RP and control subjects

- Age and vision measures
  - Age (years): 45.2 ± 11 (RP) vs. 46.8 ± 14 (Control)
  - Visual acuity (logMAR): 0.68 ± 0.88 (RP) vs. -0.15 ± 0.08 (Control)
  - Letter contrast sensitivity (logCS): 1.05 ± 0.70 (RP) vs. 1.73 ± 0.09 (Control)
  - Mean visual field extent (degrees): 13.4 ± 5 (RP) vs. > 30 (Control)
  - Number with media opacities: 8/10 (RP) vs. 0/9 (Control)

Vision measures

The average vision measures of the subjects in each group are given in Table 4. This includes the nominal values given for visual acuity and log CS for one 50-year-old subject for whom measurements could not be obtained and who had the smallest average visual field extent (four degrees). As expected, the subjects with RP showed poorer performance on all three vision measures. In addition, eight of the 10 subjects with RP had opacities in the ocular media which may have increased intraocular scatter. Within the RP group, there were significant correlations between CS and visual acuity ($r^2 = 0.64$, $p = 0.006$) and between visual acuity and visual field extent ($r^2 = 0.42$, $p = 0.04$).

Predicting mobility from vision measures

Within the RP group, neither visual acuity nor letter CS was significantly correlated with the mobility measures, while average visual field extent was significantly correlated with all mobility
Mobility with RP Black et al

mean Visual Field Extent (Degrees)

PPWS under high and low illumination as functions of the average visual field extent for the RP group (n = 10)

Error score

Mean Visual Field Extent (Degrees)

Figure 2. PPWS under high and low illumination as functions of the average visual field extent for the RP group (n = 10)

Figure 3. Error scores under high and low illumination as functions of the average visual field extent for the RP group (n = 10)

measures (r² ranged from 0.34 to 0.52) except PPWS under low illumination (r² = 0.22) (Figures 2 and 3). When all subjects were considered all vision measures correlated (Spearman) significantly with all mobility measures (r² ranged from 0.23 to 0.70). Of the vision measures, in general, average visual field extent was most highly correlated with the mobility measures.

The outcomes of the stepwise multiple regression varied between the mobility measures (Table 5). Mean visual field extent was the most common significant predictor of the mobility performance, with average visual field extent and CS combining in one analysis (low illumination PPWS) and all three vision measures combined in another (low illumination error score) of the four analyses. It is not clear why there

<table>
<thead>
<tr>
<th>Illumination</th>
<th>PPWS</th>
<th>Error score</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Mean visual field extent (p = 0.004)</td>
<td>Mean visual field extent (p = 0.006)</td>
</tr>
<tr>
<td></td>
<td>adj r² = 0.57</td>
<td>adj r² = 0.66</td>
</tr>
<tr>
<td>Low</td>
<td>Mean visual field extent (p = 0.03); letter CS (0.09)</td>
<td>Mean visual field extent (p = 0.006); letter CS (0.01); visual acuity (0.02)</td>
</tr>
<tr>
<td></td>
<td>adj r² = 0.54</td>
<td>adj r² = 0.75</td>
</tr>
</tbody>
</table>

Table 5. Results from the stepwise multiple regression analyses for each mobility measure with the clinical vision measures. The clinical vision measures remaining following the stepwise process (significance of term) and the adjusted multiple correlation coefficient (adj r²) are listed. All multiple regressions were highly significant (p < 0.005).
were such differences, but it may be due to the relatively small sample sizes. The multiple regression equations were able to explain between 54 per cent and 75 per cent of the variation in mobility performance.

DISCUSSION

Mobility performance

Mobility performance was significantly worse for subjects with RP than for the age-matched subjects with normal vision, irrespective of illumination. As subjects with RP tended to look down while following the mobility course, their restricted peripheral visual field would result in many of the obstacles, especially those placed superiorly, being outside their field of view, which might be expected to increase the number of errors. Despite this, there was no difference in the number of errors between superiorly- and inferiorly-placed obstacles. Presumably, people with RP are more cautious of peripheral obstacles along the travel path and make more eye and head scanning movements to avoid obstacles. This necessitates a reduction in walking speed (PPWS), as was found in our study. Lovie-Kitchin and colleagues similarly found that their heterogeneous low vision group was significantly slower and made significantly more errors than an age-matched control group.

Lighting conditions and adaptation to changes in lighting have been reported as contributing to major mobility problems for low vision patients, including tasks such as walking in crowds in dim illumination. Unlike the control subjects, the RP group in our study showed worse mobility performance under the lower illumination level according to the reduced efficiency (PPWS) and safety (error score) within the mobility course. The RP group made approximately 50 per cent more errors under the low illumination compared with the high illumination. This is consistent with the known reduction in CS for people with RP under low illumination, since CS correlates highly with object detection under lower illuminations. Abnormal rod function, reduced mesopic vision and delayed dark adaptation found with RP will all contribute to the difficulty in object detection. Long and colleagues, using a heterogeneous low vision group and an outdoor mobility course, found a greater increase in error scores than in our study, probably due to the larger difference in illumination levels. That the control group in our study did not show a significant change in the number of errors with illumination is consistent with the report by Cornelissen and co-workers that subjects with normal vision can detect and recognise objects at illumination levels as low as one lux, which is well below that used for our low illumination trial.

PPWS was significantly reduced for the RP group under low illumination. Haymes and colleagues found that PPWS was significantly reduced with decreasing retinal illuminance for their normally sighted subjects with a simulated constant visual field of six degrees diameter. They reduced retinal illuminance into scotopic regions to simulate the impaired night vision associated with RP, but also found reduced PPWS under the non-scotopic illuminations, similar to this study. The PPWS scores of subjects with RP measured in our study averaged around 45 per cent, while those reported by Haymes and colleagues averaged above 60 per cent. This difference is probably due to the more complex indoor course used in the current study than the ‘real world’ course used by Haymes and colleagues. Their outdoor mobility course contained no specific obstacles positioned along it and no illumination changes.

For low vision subjects with RP, Haymes and co-workers found that increasing complexity of the course resulted in a significant reduction in PPWS. However, even for their most complex course (an indoor shopping mall), the mean PPWS for their subjects with RP was 83 per cent, considerably higher than that found in our study. As well as the differences in course complexity, the different methods used to determine preferred walking speed of the low vision subjects may have affected the PPWS results. Haymes and co-workers determined preferred walking speed ‘using the sighted guide technique along an obstacle-free route’. However, for a number of their subjects, they measured a PPWS of greater than 100 per cent, that is, these subjects walked faster on the ‘real world’ mobility courses than on the obstacle-free route. It may be that the sighted guide technique underestimates the preferred walking speeds of low vision subjects, as opposed to totally blind subjects, which would result in an overestimation of PPWS.

The glare source placed in Room 2 caused a significant reduction in PPWS of the control group under both lighting conditions. Surprisingly, there was no reduction in PPWS of the RP group under the high illumination condition, though PPWS did reduce under low illumination. Adaptation to changes in lighting conditions has been reported as a major difficulty for people with low vision and for those with RP specifically. For the low illumination trial, the large illumination change from the glare source was momentarily ‘blinding’ and subjects either stopped or slowed until they could see to follow the path. The presence of media opacities, all but two of the subjects with RP, would increase intra-ocular light scatter and create disability glare, which would also reduce PPWS. It is not clear why there was no change in PPWS of the RP group under high illumination while the control group did slow under the same conditions, but it suggests that there was some unsuspected benefit from the bright lamp for the subjects with RP. It is possible that this was due to some interaction between pupil size, retinal function and ocular media opacities.

Clinical vision measures

Visual acuity was shown to have limited predictive value for mobility performance in this study. Neither Marron and Bailey nor Long and co-workers, with their heterogeneous low vision groups, found visual acuity predictive of mobility. Pelli demonstrated that it took a degradation of visual acuity down to 6/600 (2.00 logMAR) before mobility was severely impaired. Although Pelli tested normally sighted subjects with visual acuity reductions on a simple indoor maze and shop-
ping mall, his results support the notion that loss of visual acuity does not significantly influence mobility performance. In contrast, Haymes and colleagues found that visual acuity was a significant variable, explaining 25 per cent of the variance in mobility performance for their subjects with simulated RP and up to 50 per cent of the variance in PPWS for their subjects with true RP. The significant correlation in the former study can be partly attributed to the fact that visual acuity and mobility performance were retested several times for each subject under different levels of illumination, so that much of the inter-subject variability inherent in mobility performance, which was present in our study, was reduced in their study. However, this was not the case for their study of subjects with RP, although as indicated above, their mobility measure may have over-estimated the performance of their subjects with RP. Brown and co-workers, using subjects with ARM, also found a highly significant correlation between mobility performance and visual acuity. Visual acuity may be more representative of the functional visual disability of subjects with ARM than of subjects with other causes of low vision, but the relationship between visual acuity and mobility performance in different groups of low vision subjects warrants further investigation.

Contrast sensitivity was found in this study to have some predictive value in measured mobility performance, as noted by Marron and Bailey, Long and co-workers' and Haymes and colleagues. Marron and Bailey and Long and co-workers' both used peak CS measured with sinusoidal gratings. Letter CS assessed in this study with a Pelli-Robson chart at a three-metre test distance, was expected to measure CS at approximately three cycles per degree, close to the peak CS for subjects with normal vision. Marron and Bailey found that peak CS occurred at spatial frequencies ranging from 1.42 to 0.60 cycles per degree for their low vision group, while Alexander and colleagues similarly showed that the peak CS of the people with RP (with minimal or no posterior subcapsular cataract) was displaced towards lower spatial frequencies. This suggests that the Pelli-Robson chart, used at a three-metre test distance, is not measuring peak CS for our subjects with RP. Marron and Bailey found that correlations between mobility performance and CS at all of the 20 spatial frequencies they tested were less than that for the peak CS. The use of a one-metre test distance for the Pelli-Robson chart (approximately 0.9 cycles per degree) may have improved the correlation between letter CS and mobility performance in our study. Haymes and colleagues found that CS measured with the Pelli-Robson chart at a one-metre test distance and the Melbourne Edge Test, which is a good predictor of peak CS, were significantly correlated with PPWS, supporting the fact the peak CS is more predictive of mobility performance than CS measured at other spatial frequencies.

Averaged visual field extent accounted for between 50 per cent and 70 per cent of the variances in the mobility measures. With the inclusion of other vision measures, between 54 per cent and 75 per cent of the variance in mobility measures under low illumination could be explained (Table 5). Marron and Bailey and Long and co-workers' found that visual field extent alone accounted for 30 per cent and 14 per cent of mobility performance respectively in their studies. These results are lower than those found in our study, which may be explained by differences in the subject groups and in the measurements of visual field. Marron and Bailey assessed monocular visual fields using a single isopter plot on a tangent screen, with the results being expressed as the log of the percentage of visual field remaining within the central 40 degrees along 12 radii. Long and colleagues' expressed their binocular visual field measurement as the total number of points (maximum 32) seen on a bowl perimeter within a 70 degree field along eight radii. Jacobson and colleagues' and Milliken (cited by Ehrlich) reported smaller visual fields with subjects with RP when tested using lower background illumination. As we measured visual field extent with a high background illuminance (300 lux), we expected its predictive value to be greater for the higher illumination mobility measures than for the low illumination measures, but this was not apparent in our results. If the relative reduction in visual field with reduced illumination was concentric and similar in all subjects, we would expect no reduction in predictive power since the effect is only a change in the size of the coefficient. These results do not confirm earlier suggestions that computations of vision should be conducted under the same illuminance as the measurements of mobility to have any predictive value.

The results from studies which examined homogenous groups of low vision subjects are in closer agreement with the results of our study. Haymes and colleagues assessed binocular kinetic fields for their subjects with RP on a Goldmann perimeter using a large bright target. They found that a rating of the remaining visual field, based on cortical representation, accounted for 59 per cent of the variance in PPWS. Brown and co-workers' measured the binocular visual fields of their ARM subjects using an automated perimeter and scored the visual field in terms of the number of points detected, but weighted visual field areas according to their perceived importance in mobility. The visual field measures correlated significantly with both speed and errors, accounting for 63 per cent and 61 per cent respectively of the variance in these mobility measures, but the validity of weighting the visual field on the basis of practitioners' rankings is questionable. Most of the subjects with RP assessed by Haymes and colleagues and in our study had visual acuities which enabled them to maintain stable fixation during perimetry, which may not have been possible for the low vision groups used in other studies. Unlike our study, only one measurement of visual field was performed in these earlier studies and, given that visual fields are more reliable with repetition, this may also account for some variations in results. The correlation of outdoor mobility performance with visual fields measured under indoor illumination by Marron and Bailey and Long and colleagues' may also account for differences in the correlations.
found in those studies, compared with the results of Brown and co-workers\(^5\) and our study, in which indoor measures were used. Visual field extent is likely to vary under differing illuminations.\(^6\) Three of these previous studies\(^1,9,11\) found that visual field and CS measures together accounted for greater variance in mobility performance than did visual field alone, which is consistent with our results.

Based on the results from previous studies investigating the relationship between visual field and mobility, we expected the residual visual field to be highly predictive of mobility performance. Lovie-Kitchin and colleagues\(^5\) found that mobility performance was significantly influenced by the total visual field, with smaller visual fields relating to poorer mobility performance. They found that both time and errors gave significant correlations ($r^2 = 0.30$ and 0.58, respectively), as did PPWS and error score in our study ($r^2$ ranged between 0.50 and 0.70). Differences between our results and those of Lovie-Kitchin and colleagues\(^5\) may be due to the use of PPWS scores and a homogenous low vision group in this study, along with variations in the indoor course designs. Alfano and Michel\(^6\) and Pelli\(^10\) showed that restrictions of the peripheral visual field of normally sighted subjects affect mobility performance. Although previous studies relating mobility performance with visual field differ in the extent of visual field considered important for mobility, they all consistently showed that smaller visual fields correlate with poorer mobility, as was confirmed in our study.

Vision measures accounted for up to 75 per cent of the mobility performance in our study. The remaining variance is presumably accounted for by measurement errors, visual capabilities not measured in our study and other factors such as personality, confidence or the extent to which people take risks. The use of questionnaires to assess these factors may have been useful, although Haymes and colleagues\(^13\) found no significant relationships between mobility performance and measures of personality, locus of control or intelligence. Because mobility was measured in a risk-free environment for the current study, these personality factors may not have influenced mobility performance as much as they might in the real world, where real dangers are encountered.

**CONCLUSIONS**

Our study demonstrates that mobility performance, measured in terms of safety (error score) and efficiency (PPWS) on an indoor mobility course, is significantly worse for people with RP than for people with normal vision, especially under the low illumination used in this study. The presence of a glare source further reduced mobility performance under low illumination for the subjects with RP but not under higher illumination. As found in previous studies of low vision subjects, average visual field extent and CS predicted mobility performance on our indoor course. These results are important when considering strategies to enhance the mobility of persons with RP, as external factors such as reduced illumination or illumination changes should be taken into account. Consideration needs to be given to the design of buildings and shopping centres, with particular consideration being given to lighting, contrast, obstacle placement and terrain variations.

**ACKNOWLEDGEMENTS**

Many thanks to Graeme Ferguson, president of the Retinitis Pigmentosa Association of Queensland, for his kind assistance and to all of the subjects who participated in this study.

**REFERENCES**


Author's address:
Associate Professor J Lovie-Kitchin
Centre for Eye Research
School of Optometry
Queensland University of Technology
Locked Bag 2
Red Hill 4059
QUEENSLAND