Visual Field Size Criteria for Mobility Rehabilitation Referral

Jan E. Lovie-Kitchin*, Grace P. Soong*, Shirin E. Hassan*, and Russell L. Woods*

ABSTRACT

**Purpose.** To investigate evidence-based visual field size criteria for referral of low-vision (LV) patients for mobility rehabilitation.

**Methods.** One hundred and nine participants with LV and 41 age-matched participants with normal sight (NS) were recruited. The LV group was heterogeneous with diverse causes of visual impairment. We measured binocular kinetic visual fields with the Humphrey Field Analyzer and mobility performance on an obstacle-rich, indoor course. Mobility was assessed as percent preferred walking speed (PPWS) and number of obstacle-contact errors. The weighted kappa coefficient of association (κ) was used to discriminate LV participants with both unsafe and inefficient mobility from those with adequate mobility on the basis of their visual field size for the full sample and for subgroups according to type of visual field loss and whether or not the participants had previously received orientation and mobility training.

**Results.** LV participants with both PPWS <38% and errors >6 on our course were classified as having inadequate (inefficient and unsafe) mobility compared with NS participants. Mobility appeared to be first compromised when the visual field was less than about 1.2 steradians (sr; solid angle of a circular visual field of about 70° diameter). Visual fields 0.23 and 0.63 sr (31 to 52° diameter) discriminated patients with at-risk mobility for the full sample and across the two subgroups. A visual field of 0.05 sr (15° diameter) discriminated those with critical mobility.

**Conclusions.** Our study suggests that: practitioners should be alert to potential mobility difficulties when the visual field is less than about 1.2 sr (70° diameter); assessment for mobility rehabilitation may be warranted when the visual field is constricted to about 0.23 to 0.63 sr (31 to 52° diameter) depending on the nature of their visual field loss and previous history (at risk); and mobility rehabilitation should be conducted before the visual field is constricted to 0.05 sr (15° diameter; critical).

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The visual field size (VF) at which safe and efficient mobility first becomes compromised is not known. By using a simple visual field constriction that did not incorporate eye movements, Pelli20 reported that the mobility of his normally sighted (NS) participants was not impaired until the visual field was 10° diameter on an indoor course and 4° on an outdoor course. By using a virtual environment and simulated visual field restriction, again, without eye-movement tracking, Hassan et al.21 reported that mobility became impaired at 30 to 11° diameter. Lovie-Kitchin et al.14 examined visual field loss in nine participants with heterogeneous causes of LV and nine NS participants and found that the central 74° and inferior midperipheral zones of the visual field contributed most significantly to mobility performance. They suggested that people with visual field loss extending into those paracentral and pericentral areas were likely to have difficulty traveling safely and efficiently by themselves. These findings were based on a small sample with the visual field examined in large subdivisions.
Mobility rehabilitation for people with LV can involve a range of training approaches and optical and/or non-optical aids. The most common form is orientation and mobility (O&M) training that involves the use of remaining vision and other senses, commonly in conjunction with sighted guides or long or short canes.\(^4^2\) Other mobility aids include those to expand the visual field, which should improve detection of potential collisions for hemianopia\(^4^3–4^8\) and “tunnel vision,”\(^2^9–3^9\) magnifying telescopes, which can assist with orientation (way finding),\(^4^0\) and low-light aids that can assist people with poor night vision.\(^3^1,^4^2\) Eye movement (scanning) training for mobility rehabilitation has been investigated for hemianopia\(^4^3–4^6\) and tunnel vision.\(^3^4,^4^7\) There have been conflicting research results as to whether O&M training is beneficial\(^3^4,^4^0,^4^8,^4^9\) or not.\(^5^0,^5^1\) The limited evidence of a benefit probably reflects the lack of well-designed objective evaluations of O&M training,\(^5^2\) rather than a lack of benefit; certainly, patients have reported a benefit in at least one study of older adults.\(^4^9\) Despite the limited evidence of a benefit from O&M training or the various mobility devices, and the expense of mobility rehabilitation, referral is still warranted, as the reduced social participation and loss of quality of life that is a consequence of reduced mobility is significant for individuals and society. Timely and efficient referral for mobility rehabilitation will optimize the use of limited rehabilitation resources and reduce societal costs. Identifying the best time for referral now will allow practitioners to be ready for future mobility rehabilitation strategies.

There have been no studies to objectively determine guidelines for referral of LV patients for mobility rehabilitation. Based on interpretation of correlations obtained for 18 people with LV (retinitis pigmentosa), Haymes et al.\(^8\) recommended that people with a visual field diameter of <20° be referred. It is a common clinical practice to use visual field criteria of 15 to 10° diameter for referral of LV patients who require mobility rehabilitation.\(^5^3–5^5\) These criteria may have been influenced by the visual field criterion for eligibility for social welfare assistance in Australia and the United States, which is 20° diameter (legal blindness). Such criteria for mobility rehabilitation referral may not be appropriate, because most people with such small visual fields already have substantial mobility problems. We suggest that LV patients should be referred for mobility rehabilitation assessment, and if necessary, receive training, when they are at risk of inadequate mobility skills for independent travel, rather than when their mobility is already severely impaired (critical). We propose that useful guidelines (referral criteria) of that at-risk status can be determined from VF.

Our study aimed to determine the VF that places patients at risk of impaired mobility. We used mobility measures to discriminate LV participants who had unsafe and inefficient (inadequate) mobility from those participants (with LV and NS) who had adequate mobility. By assuming different costs associated with referral decisions, we propose visual field criteria for patients whose mobility is at risk (probably inadequate) and for those whose mobility is critical (definitely inadequate).

**METHODS**

**Participants**

One hundred and nine participants with LV, aged 25 to 88 years (median, 67 years), were recruited from the Queensland University of Technology (QUT) Vision Rehabilitation Centre, Guide Dogs for the Blind Association of Queensland, and Retina Australia Queensland. The LV participants had a wide range of conditions that included age-related macular degeneration, retinitis pigmentosa, glaucoma, macular dystrophy, optic atrophy, and hemianopia (Table 1). Forty-one NS participants, aged between 27 and 90 years (median, 68.5 years), with no ocular pathology were recruited from the QUT Optometry Clinic. There was no significant difference in the age distributions of the LV and NS groups (Wilcoxon test, \(z_{49} = 0.38\), and \(p = 0.70\)).

Common clinical opinion has been that mobility problems only occur with (substantial) peripheral visual field loss, but a few studies have shown that central visual field loss (CFL) can affect mobility performance.\(^1^2,^1^4,^5^6\) Therefore, in addition to analyzing the data for the full LV sample, we also examine the data in two visual field subgroups, those with CFL alone (\(n = 35\)) and the remainder with peripheral loss or mixed peripheral and central loss (\(n = 74\); Table 1). Of the 109 LV participants, 48 had previous O&M training. The authors had no involvement in that training, and the details of the training and its outcomes were not available to the authors. Some participants would have received sighted guide instruction only, whereas others had some O&M instruction with short or long canes specific to their travel routes, and the remaining may not have completed training. For the mobility assessment, participants were not allowed to use any mobility aids. Thus, we also examined the data for the LV participants in two mobility subgroups, those who had O&M training (\(n = 48\)) and those who did not have training (\(n = 61\); Table 1).

No participants had a physical disability that impaired their ability to walk unaided. Participants wore their habitual spectacle correction during mobility assessment but were not allowed to use any mobility aids; they had to use their vision to negotiate the unfamiliar course. The nature and any possible consequences of

**TABLE 1.**

Median (range) age, VA, VF, PPWS, and number of mobility-course errors of the 41 NS (NS and all 109 LV participants and for the subgroups of LV participants with CFL only or PMFL and those who did or did not receive O&M training.

<table>
<thead>
<tr>
<th>Participants</th>
<th>n</th>
<th>Age (y)</th>
<th>VA (logMAR)</th>
<th>VF (sr)</th>
<th>PPWS (%)</th>
<th>Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS</td>
<td>41</td>
<td>68 (27–90)</td>
<td>−0.02 (−0.30 to 0.30)</td>
<td>2.78 (1.40–3.41)</td>
<td>51 (38–74)</td>
<td>0 (0–5)</td>
</tr>
<tr>
<td>All LV</td>
<td>109</td>
<td>67 (25–88)</td>
<td>0.78 (−0.02 to 2.56)</td>
<td>1.10 (0–2.94)</td>
<td>37 (12–65)</td>
<td>3 (0–78)</td>
</tr>
<tr>
<td>CFL only</td>
<td>35</td>
<td>79 (40–88)</td>
<td>1.02 (0.04 to 1.8)</td>
<td>1.73 (2.72)</td>
<td>41 (23–58)</td>
<td>3 (0–16)</td>
</tr>
<tr>
<td>PMFL</td>
<td>74</td>
<td>58 (25–88)</td>
<td>0.65 (−0.02 to 2.56)</td>
<td>0.35 (2.94)</td>
<td>36 (12–65)</td>
<td>4 (0–78)</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>48</td>
<td>55 (25–87)</td>
<td>0.84 (−0.02 to 2.56)</td>
<td>0.27 (2.41)</td>
<td>31 (12–58)</td>
<td>6 (0–78)</td>
</tr>
<tr>
<td>No O&amp;M</td>
<td>61</td>
<td>73 (26–88)</td>
<td>0.74 (0 to 1.66)</td>
<td>1.64 (2–94)</td>
<td>42 (23–65)</td>
<td>2 (0–19)</td>
</tr>
</tbody>
</table>
the study were explained to all participants who gave written informed consent before participating in the study. The research followed the tenets of the Declaration of Helsinki and was approved by the QUT Human Research Ethics Committee.

**Visual Field Measurement**

We assessed the binocular VF of each participant by kinetic perimetry using the semiautomated kinetic perimetry program of the Humphrey Field Analyzer (HFA). Participants were positioned as for right eye testing, and this eye was monitored for stable fixation, controlled by means of a large fixation target that was well within their resolution limits. The stimulus used was IV 4 E (4.6 mm diameter, 3.2 cd/m²). We determined each participant’s isopter (outer margin of visual field area) to this target by initiating the stimulus movement from 75° nasally and temporally and 55° superiorly and inferiorly (Fig. 1). To detect any scotoma within the isopter, we presented a static suprathreshold stimulus for 1 s at points selected within the isopter (total extent). When a non-seeing area was detected within the isopter, the boundary of the scotoma was defined by the “map scotoma” mode in which the stimulus was moved in the eight principal meridians from the unseen point until the participant indicated its detection. The outcome of this procedure for one participant with mixed peripheral and CFL is shown in Fig. 1.

To better represent the functional visual field, especially those with CFL only or mixed visual field loss, the VF for each participant was calculated as a solid angle [steradians (sr)]. By using the HFA data, custom software was used to calculate the solid angle subtended by the isopter and the solid angles of any measured scotomas. The remaining visual field was calculated by taking the difference between the isopter and any scotomas within the isopter in sr. This solid angle calculation is equivalent to calculations of retinal area from visual field measurements.

By using that procedure, the maximum possible VF subtended a solid angle of 3.47 sr (127° diameter). Our NS participants had VFs between 3.4 sr (125° diameter) and 1.4 sr (78° diameter), with, as expected, a non-linear trend for decreasing size with increasing age. Because of the severe vision loss, 14 LV participants were unable to see the stimulus presented; so, they were assigned a value of zero for their VF. Although there was no measurable visual field for those test conditions, these participants still had some useable vision.

**Mobility Assessment**

We assessed each participant’s mobility performance first on a 20-m unobstructed straight corridor, to determine preferred walking speed, and then on a 79-m indoor obstacle course with high

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**FIGURE 1.**

The visual field of a LV participant. The outer extent of the gray area is the maximum binocular kinetic visual field that could be measured using our procedure with the HFA. The white area inside that maximum extent is the patient’s visual field. Circular visual fields with no central scotoma that were the size of the dashed circles would have solid angles of 1.21 sr (72° diameter), 0.63 sr (52° diameter), or 0.05 sr (15° diameter). Participant 68 was aged 83 years, had glaucoma and diabetic retinopathy, had a PPWS of 31%, made eight errors on the mobility course, and shows an example of a mixed visual field loss.

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*As solid angles are unfamiliar to most clinicians, when we report visual field sizes the diameter of a circular visual field that subtends the same solid angle is included in parentheses. Conversions between solid angle and these “equivalent” circular visual field diameters are given by the equation solidangle = 2π[1 − cos(Θ/2)], where Θ is the diameter of a circular visual field with that solid angle.*
obstacle density. The design features of the obstacle course and procedures for assessing the participants’ performances have been reported previously. As we were interested in the relationship between vision and mobility, participants were not allowed to use any mobility aids (e.g., long cane). We assessed mobility performance on the obstacle course using the following measures:

a. Percentage preferred walking speed (PPWS). b. Number of errors (primarily obstacle contacts).

We considered that measures of both walking efficiency and obstacle avoidance were needed as adjustments to both aspects of mobility are required to be made by people with LV. However, given that walking speed and error rates are highly correlated (in our data: Spearman, \( r = -0.59 \); Fig. 3), it is not certain that these measures of efficiency and safety are independent. Because of the high obstacle density, the highest PPWS on the obstacle course was 74% for a participant with NS, and the maximum number of errors was 78 by a LV participant with retinitis pigmentosa and no remaining visual field to our stimulus.

**Data Analysis**

PPWS was not significantly different from a normal distribution (Kolmogorov-Smirnov test, \( p > 0.05 \)); however, VF and number of errors were significantly different (\( p < 0.05 \)). Therefore, non-parametric statistical tests were used where appropriate (e.g., Wilcoxon test and Spearman correlation \( r \)).

To determine the VF that was predictive of inadequate mobility, we used a two-step approach that incorporated signal detection analyses. The first analysis discriminated between the LV and NS participants on the basis of their mobility performance, by making the assumption that mobility performance of NS participants was the same as those with adequate mobility, on the basis of VF. With \( r = 0.1 \), LV participants were defined as having inadequate mobility if they had both a PPWS below the PPWS criterion and more errors than the number-of-errors criterion, i.e., both inefficient and potentially unsafe mobility. By using that categorization of mobility performance, second \( \kappa \) analyses, with relative-cost weightings of 0.9, 0.5, and 0.1, were used to discriminate LV participants with inadequate mobility from LV participants with adequate mobility, on the basis of VF. With \( r = 0.9 \), the second \( \kappa \) analysis places an emphasis on high sensitivity (good identification of those with poor mobility). Estimated relative costs and the calculation of \( \kappa \) are described in the Appendix (available at http://links.lww.com/OPX/A37). This weighting was used to determine the “at-risk” VF. The estimated costs for \( r = 0.9 \) assumed that the cost of referral was low relative to the cost of failure to refer a patient in need of mobility rehabilitation. This may not be true when there are insufficient mobility rehabilitation resources and could be tempered by the repeated opportunities for referral that occur with good patient management. With repeated patient visits, the cost of the failure to refer at one visit may be relatively small. When the second \( \kappa \) analysis was performed with a relative-cost weighting, \( r = 0.1 \), the analysis emphasized specificity (to lower the incorrect identification of those without poor mobility). This weighting was used to determine the “critical” VF. The relative-cost weighting of \( \tau = 0.5 \) allows comparison with other studies, as most signal detection analyses do not include a relative-cost weighting, which is equivalent to \( \tau = 0.5 \).

Confidence intervals (95%) for \( \kappa \) and optimal criteria were found using a bootstrap procedure. Given our heterogeneous group of LV participants, we repeated the determination of optimal visual field criteria for those LV participants with peripheral and/or mixed visual field loss (P&MFL; i.e., omitting those with only CFL) and for those who had not received O&M training.

**RESULTS**

The median VFs and mobility performance measures for the LV participants and the subgroups are shown in Table 1. The full LV group had significantly reduced VF (Wilcoxon \( z_{149} = 7.9, p < 0.001 \)), made significantly more errors (\( z_{149} = 6.3, p < 0.001 \)), and walked significantly less efficiently (\( z_{149} = 6.6, p < 0.001 \)) than the NS group. The distributions of the two mobility measures showed substantial overlap between the LV and NS groups (Fig. 2). Some LV participants had little visual field decrement and were able to travel as efficiently and safely as their NS counterparts, whereas some NS participants traveled less efficiently than most NS participants and made up to five errors. They tended to be older and walked more cautiously in the cluttered environment as expected.

As expected, VF was significantly correlated with both PPWS (Spearman correlation, \( \rho_{149} = 0.65 \) and \( p < 0.001 \)) and number of errors (\( \rho_{149} = 0.67 \) and \( p < 0.001 \)). The regression models for these relationships are as follows:

\[
VF = -0.685 + 0.055 \text{PPWS},
\]

and

\[
VF = -0.783 + 1.61 \cdot \log_{10} \left( \frac{100}{1 + \text{errors}} \right)
\]

where, the number of errors was transformed to reduce the impact of the skew distribution.

**Safe and Efficient Mobility Performance**

As shown in Fig. 2 and Table 2, PPWS of 38% and six errors had the highest \( \kappa_{0.1} \) of 0.84 and 0.73, respectively, and thus best discriminated the performance of the full LV group from the NS participants. Kappa coefficients between 0.60 and 0.80 are considered to show “substantial” agreement and between 0.8 and 1.0 as having “almost perfect” strength of agreement. These optimal criteria produced high specificity as expected (\( r = 0.1 \)) with no NS participant being misclassified but only fair to moderate sensitivity. Of the 109 LV participants, these criteria categorized 67 (61%) as having inadequate mobility, whereas the remaining LV participants had adequate mobility, and no NS participant had inadequate mobility. By using the significant relationships between VF and the mobility measures given above, these criteria correspond to VFs of 1.41 sr (78° diameter) for PPWS and 1.08 sr (68° diameter) for errors.

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VF for Predicting Unsafe, Inefficient Mobility

The VFs of the 27 LV participants with inadequate mobility (failed both criteria) had some overlap with the 82 LV participants with adequate mobility (passed one or both criteria). By using the at-risk criterion (r = 0.9), the VF that best discriminated between those LV participants with and without adequate mobility was 0.63 sr (52° diameter) with a k0.9 of 0.74 (Fig. 4 and Table 3). The at-risk visual field criterion had high accuracy, 0.79 (CI: 0.61 to 0.94), but, of the 44 LV participants with a VF <0.63 sr (52° diameter), 20 LV participants with adequate mobility were categorized incorrectly, a positive predictive value of only 0.55 (Table 3). When this second r analysis was conducted with relative-cost weightings, r, of 0.5 (used when relative costs are not known) and 0.1 (emphasizes specificity), the optimal visual field criteria were much smaller (Table 3). As always in such analyses, the improved specificity and positive predictive value was at the expense of sensitivity and negative predictive value. By using the critical criterion (r = 0.1), the VF that best discriminated between those LV participants with and without adequate mobility was 0.05 sr (15° diameter; Table 3). This critical visual field criterion had high accuracy, 0.90 (CI: 0.81 to 0.94), but, of the 25 LV participants with inadequate mobility, only 17 were categorized correctly, a sensitivity of only 0.68 (Table 3).

For the subgroup of LV participants with P&MFL (n = 74), inadequate mobility could be discriminated (k0.9 = 0.74), as well as when the full, heterogeneous LV group was included and the optimal visual field criterion was smaller: 0.38 sr (40° diameter; Table 3, Figs. 3 and 4). This at-risk visual field criterion is within the 95% confidence limits of the analysis that used all 109 LV participants (Table 3), although most clinicians would probably consider the difference between a visual field diameter of 52 and 40° as functionally significant. Compared with the 35 LV participants with CFL only, the 74 LV participants with P&MFL were younger (Mann-Whitney, z108 = 4.9, and p < 0.001), had better VA (z108 = 3.5 and p < 0.001) and smaller visual fields (z108 = 4.5 and p < 0.001), and on the obstacle course made more errors (z108 = 2.20 and p = 0.028; Table 1).

When the LV participants who had not been referred for O&M assessment (n = 61), inadequate mobility could be discriminated (k0.9 = 0.72) almost, as well as when the LV participants who had received O&M training were included (k0.9 = 0.74; Table 3, Figs. 3 and 4). This at-risk visual field criterion was smaller [0.23 sr (31° diameter)] than when all 109 LV participants were included [0.63 sr (52° diameter)] and, again, would probably be considered significantly so by many clinicians, but it is within the 95% confidence limits of that analysis (Table 3). Compared with the 61 LV participants who had not been referred for O&M assessment, the 48 LV participants who had been referred were younger (Mann-Whitney, z108 = 2.70, and p = 0.007), had smaller visual fields (z108 = 4.5 and p < 0.001), and on the obstacle course had a lower PPWS (z108 = 4.0 and p < 0.001) and made more errors (z108 = 4.0 and p < 0.001; Table 1). The optimal visual field criteria for

![Figure 2](image_url)

**FIGURE 2.**
Frequency distributions and weighted kappa coefficients (k0.1) for (A) PPWS and (B) number of errors for the NS and LV groups. The highest point on each kappa curve (thick line) indicates the quality of the discrimination (k0.1) and the corresponding optimal criterion (mobility score). Values associated with the optimal criteria are shown in Table 2.

**TABLE 2.**
Results of the first-weighted kappa analysis that discriminated LV participants from NS participants on the basis of the two mobility measures, PPWS, and number of errors (Fig. 4)

<table>
<thead>
<tr>
<th>Mobility measure</th>
<th>Optimal criterion</th>
<th>k0.1</th>
<th>Sensitivity (CI)</th>
<th>Specificity (CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPWS</td>
<td>38 (37–41)</td>
<td>0.84 (0.79–0.90)</td>
<td>0.51 (0.43–0.64)</td>
<td>1 (1–1)</td>
</tr>
<tr>
<td>No. errors</td>
<td>6 (3–6)</td>
<td>0.73 (0.66–0.83)</td>
<td>0.35 (0.28–0.64)</td>
<td>1 (0.93–1)</td>
</tr>
</tbody>
</table>

Confidence intervals (95%) are shown in parentheses.
the relative-cost weightings of $r = 0.5$ and 0.1 (for higher specificities) were robust across the full LV sample and the different subgroups (Table 3).

As shown in Fig. 3, three LV participants with VFs $>0.63$ sr (52° diameter) had inadequate mobility, each of them having borderline mobility performance. Of the 18 LV participants with VF of $<0.05$ sr (15° diameter), three had adequate mobility (all three passed the error criterion <6 errors but failed the PPWS criterion <38%).

DISCUSSION

Our findings confirm those from previous research\(^8\)–\(^{19}\) that the visual field is an important predictor of mobility performance of people with LV. By using the first of two weighted kappa coefficient of association ($\kappa_r$) analyses, we found mobility performance scores that discriminated LV participants with mobility that was worse than all of the NS participants (inadequate mobility). To our knowledge, no previous research has defined mobility impairment in terms of measured performance, although it is important to note that these performance scores are a function of our obstacle course, so cannot be extrapolated to other indoor or outdoor mobility courses. From these mobility scores, we derived the VF at which safe or efficient mobility began to be compromised: less than about 1.2 sr [70° diameter; from 1.41 sr (78° diameter) for PPWS and 1.08 sr (68° diameter) for errors]. This agrees well with the findings of Lovie-Kitchin et al.\(^{14}\) who found that the central 74° diameter visual field contributed strongly to the mobility performance of their (small) heterogeneous LV group. The second $\kappa_r$ analysis gave visual field criteria that discriminated those LV participants with inadequate mobility from those with adequate mobility (Table 3). For the full LV group, this analysis suggested that when the VF was $<0.63$ sr (52° diameter), mobility performance was at risk (probably inadequate) and when $<0.05$ sr (15° diameter), it was critical (definitely inadequate). This analysis improves on our earlier report of a subset of the 109 LV and 41 NS participants in which we reported that a visual field of about 0.59 sr (50° diameter) discriminated (equal sensitivity and specificity) between 79 LV and 20 NS participants.\(^{70}\)

When those LV participants with CFL only were removed from the analysis, a slightly smaller visual field criterion for at-risk mobility was found. For those with P&MFL, the criterion was 0.38 sr (40° diameter; Table 3). This suggests that if there is central involvement in the visual field loss, referral for assessment should be earlier than if there is peripheral restriction only. This may seem counterintuitive, but these findings indicate that for those participants with predominantly intact central visual field, once their field loss involves the central (40° diameter) field, mobility is likely to be impaired. Lovie-Kitchin et al.\(^{14}\) found that the central 37°
Inadequate mobility was defined as a PPWS of < 0.23 sr (31° diameter; Table 3 and Fig. 4). If we accept that a visual field < 0.23 sr is associated with mobility rehabilitation at the appropriate time would be useful. A sufficiently reduced visual field provides a simple and sensitive clinical predictor of those with inadequate mobility. Thus, we propose that people with a VF < 0.23 to 0.63 sr (<31° to 52° diameter), depending on other factors such as previous referral or presence of CFL, are at risk of having inadequate mobility for independent travel, i.e., both unsafe and inefficient, suggesting that mobility assessment is warranted at this point. Although this is a larger VF than is common for mobility rehabilitation referral, we consider these people may be at risk and expect that early assessment will provide better long-term outcomes. Such assessment would determine if mobility rehabilitation, such as O&M training or mobility aids, is required to maintain safe independent travel. Even with our at-risk VF criterion, many of those referred would have reasonable mobility skills, because the positive predictive value was only 0.55 (Table 3). The critical VF [0.05 sr (<15° diameter)] would produce few incorrect referrals, as the positive predictive value was > 0.80 for the full LV sample and the subgroups. VFs of about 0.024 sr (10° diameter) to 0.054 sr (15° diameter), the criteria used by many eye care practitioners for referral of people with LV for mobility rehabilitation services, is consistent with our critical VF criterion. However, if the critical VF was used for first referral, many people with inadequate mobility would not have been referred, because the sensitivity was only 0.68 (Table 3). By the time theirVF has reduced to the critical VF, most people will have altered their daily activities, particularly independent travel, and may be unable to regain their previous level of independence, even following mobility rehabilitation. We suggest that people be referred for assessment at or before the at-risk VF, rather than waiting for a critical VF (as is the common current clinical practice), by which time many people could be endangering themselves if traveling independently.

As our suggested VF criteria are based on only this one study, with a small, convenience sample of participants with heterogeneous causes of LV, whose visual fields were measured for only one target size and mobility assessed on an indoor mobility course with high obstacle density, further research with other population samples and using other methodologies is required to test the veracity of our findings. Further research is needed to assess the effect of mobility training on mobility rehabilitation outcomes. When those who had received O&M training were removed from the analysis, the visual field criterion for at-risk mobility also reduced to 0.23 sr (31° diameter; Table 3 and Fig. 4). If we accept the premise that O&M training improves mobility performance on an unfamiliar course—and this has yet to be proven51,52—and the expectation is that those who received O&M training would have walked more efficiently and made fewer errors on our course than if they had not received O&M training, and therefore were less likely to be identified as having inadequate mobility than if they had not had O&M training. Those participants with O&M training had smaller visual fields (Table 1) as expected. Therefore, including these participants (with the assumption that O&M training provided a benefit in our mobility assessment) is likely to have skewed the findings of the analysis that included all 109 participants (Table 3) to those with smaller visual fields performing better than expected and has the possibility of making the visual field criteria based on the full LV group’s data more conservative (biased toward smaller visual field criteria). Fig. 4 shows that, although the at-risk visual field criteria varied widely between the full and subgroup analyses (Table 3), the underlying kappa functions were quite similar, suggesting that the effects found here are robust. It is likely that many eye care practitioners for referral of people with LV for mobility rehabilitation services is consistent with our critical VF criterion. However, if the critical VF was used for first referral, many people with inadequate mobility would not have been referred, because the sensitivity was only 0.68 (Table 3). By the time their VF has reduced to the critical VF, most people will have altered their daily activities, particularly independent travel, and may be unable to regain their previous level of independence, even following mobility rehabilitation. We suggest that people be referred for assessment at or before the at-risk VF, rather than waiting for a critical VF (as is the common current clinical practice), by which time many people could be endangering themselves if traveling independently.

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of our findings. Although we cannot state categorically that mobility performance on our indoor course was representative of performance in real-world environments, similar results from indoor and outdoor courses have been reported.\textsuperscript{15,16} We have no reason to believe that our participants performed any differently from their normal unaided mobility behavior, as we instructed them. The error score in our study was comprised primarily of contacts with static obstacles. Other mobility incidents such as disorientation, balance instability, hesitations, and hand searches, which are relevant to safe, independent travel,\textsuperscript{77–79} could be included as a part of future mobility assessments.\textsuperscript{80} Although Kuyk et al.\textsuperscript{15,16} have reported similar results from indoor and outdoor courses, in future studies, the visual field criteria should be examined with a mobility course that includes moving obstacles.

In this study, for the first time, we have begun to establish the vision requirements for mobility, albeit in a limited way as visual field was the only visual function investigated. Other vision measures such as contrast sensitivity,\textsuperscript{8–12,81} visual search,\textsuperscript{15,16} attention,\textsuperscript{17,82} and cognitive ability\textsuperscript{19} should be incorporated in future studies, because these measures have been found to impact on mobility of people with LV. However, the use of multiple tests does not necessarily produce better discrimination, and it can reduce the cost benefit.\textsuperscript{83} Also, requiring multiple tests increases the workload of the referring practitioner and makes clinical interpretation of mixed results difficult.

Visual impairment is usually defined by a VA range (e.g., 20/60 to 20/200) with no consideration of VF. Blindness (severe visual impairment) is usually defined as worse than a VA criterion (e.g., 20/200 and sometimes by a VF [e.g., <0.10 sr (<20° diameter)]). Our objectively determined at-risk and critical criteria may be the VFs that correspond to definitions of visual impairment and blindness. Although there is reasonable clinical consensus on VA referral criteria,\textsuperscript{53–55} we are not aware of any (evidence-based) objective determinations of such VA criteria for vision rehabilitation. Recently, the Social Security Administration (United States) allowed the use of static perimetry to assess legal blindness. As most studies that have related visual field extent to mobility performance have used kinetic perimetry, and there are differences between kinetic and static perimetry,\textsuperscript{83–85} it is not clear that our results can be directly translated to a visual field extent found with static perimetry.

In summary, based on this evidence-based analysis, we suggest the following clinical guidelines for eye care practitioners. First, people with a binocular VF less than about 1.2 sr (70° diameter) have not received mobility rehabilitation, as their mobility may be compromised. Second, we suggest that people with a VF <0.23 to 0.63 sr (<31 to 52° diameter) be considered for referral for mobility assessment and possible mobility rehabilitation, as they are at risk of mobility difficulties. For this group, referral is more likely to be necessary if there is central involvement of the visual field loss and/or if they have changed their normal travel routes. Finally, we suggest that if people with a binocular VF <0.05 sr (15° diameter) have not received mobility rehabilitation, they should be offered immediate referral. Further research is warranted, because our study was limited in a number of ways, as detailed above, and our recommendations cannot be considered definitive.

APPENDIX

The appendix is available at http://links.lww.com/OPX/A37.

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REFERENCES


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