Target Search and Identification Performance in Low Vision Patients

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PURPOSE. To introduce a novel approach to topographic function assessment in visual impairment that requires neither fixation nor reading.

METHODS. One hundred thirty-five consecutive low vision patients with varying diagnoses and 30 control subjects of comparable median age participated. Performance was measured in a search task that required finding and identifying visual targets which appeared consecutively on a monitor in 32 locations of the central field of gaze. The task specifically discourages steady fixation and the subjects could make eye movements as needed to locate targets. Target size was always double the size threshold, and no manual action was required. The best attainable reading speed at any size was routinely measured (MN-read). Main outcome measure was response latency necessary to solve the task. Data were median latencies and sums of all latencies.

RESULTS. Measurements yielded a wide variety of performance levels, with a factor of 14 to 16 between best and worst performers. The highest correlation existed between median response latency in the search task and best attainable reading speed. Only a weak correlation was found between performance and visual acuity. No statistically significant correlations were found with age or diagnosis.

CONCLUSIONS. The “search-and-identify” paradigm and continuous text reading share an important mechanism that determines performance in both tasks. The authors hypothesize that the factor enabling patients to perform well in both paradigms is ocular movement skill and/or eye movement strategy. Results show that the search test is a useful tool for the easy assessment of impaired vision independent of language, level of literacy, and reading habits. (Invest Ophthalmol Vis Sci. 2011;52:7603–7609) DOI:10.1167/iovs.10-6728

Visual impairment can be characterized as diminished functional vision.1 This characterization cannot be achieved by measuring visual functions like visual acuity alone, although it is often used as a substitute estimate of functional vision. Characterizing visual impairment needs to include an assessment of the patient’s ability to interact with the visual environment. The latter should include the capability to learn, to remember, and to respond to changing stimulus conditions.

The most important response of this kind are eye movements, which are elicited by attracting visual attention to a presumably interesting target on the peripheral retina.2–4 It has been reported that patients with low vision can perform feature search.5 In vision rehabilitation, it has also been shown that search performance can be trained.6 Being able to make eye movements can decide whether training is effective or not.7 The process may involve the adoption of new eye movement strategies.8–10 This article aims to introduce a novel approach toward the assessment of visual impairment by removing some traditional barriers.

A realistic way to measure visual impairment calls for topographic testing without the constraint of strict fixation. The history of topographic vision assessment has been dominated by the necessity to bring individual responses into spatial register to preserve spatial relations in the visual field. This is done by requiring stable central fixation. This requirement has been an essential issue in perimetry since its development in the mid-19th century (for its history, see http://webeye.ophth.uiowa.edu/ips/PerimetryHistory). However, steady fixation is hard to accomplish for most patients with low vision, especially those with central scotomas and damaged foveal vision. Consequently, these patients may use a preferred retinal locus (PRL) to accomplish the goal,11,12 which is known to be less accurate than in subjects with an intact fovea.13–15 Vision assessment can be made easier by using the physiological blind spot in conventional perimetry as reference scotoma,16 or by offering the patient abundant peripheral landmarks to enable them to monitor their own fixational stability.17–19 Nonetheless, unstable fixation during topographic vision assessment has remained a problem that can be overcome only by an instrument that does not require calibration (i.e., a scanning laser ophthalmoscope [SLO]),20 especially if it can compensate for fixational inaccuracies.21 But what do you do if you have no SLO available?

A second important issue is the fact that the task in perimetry is to simply detect the appearance and disappearance of a target during steady fixation. In real life, our eyes are always moving, and the movement can effectively minimize the impact of field disruptions on performance of visually-guided activities, such as reading. To differentiate perceptual deficits in patients with low vision more finely, it is desirable to use a task that is similar to a real-life viewing situation and that makes the test more sensitive by making the task more demanding. A simple step is to require solving a discrimination task, where a positive identification is necessary.17,22,23 Increasing the difficulty can be achieved by reducing the target contrast.18,24

The “Macular Search Test” paradigm comprises two tasks, i.e., first to find the target, and then to identify it. Hence, this paradigm abolishes the demand for steady fixation by allowing patients to make any eye movements they need to solve these tasks. What distinguishes individual trials from each other is the location where the target first appears. The outcome measure for performance in this procedure is the response latency...
(i.e., the interval from target appearance to the correct response).

To allow direct comparison between patients, it was a further goal to make measuring the latency independent of target size, or visual acuity. We achieved this by letting every patient perform at a level referenced to their own acuity threshold. The results show that response latencies can be dramatically different even if visual acuity is removed as a major influence.

Preliminary reports of parts of these data were communicated elsewhere (MacKeben M, et al. IOVS 2005;46:ARVO E-Abstract 3690).25

**METHODS**

**Subjects**

One hundred thirty-five consecutive patients (44 men, 91 women) were recruited from our Low Vision Rehabilitation Service. Their age range was 18 to 98 years, with a distribution strongly skewed toward older ages (median, 80.0 ± 14 years interquartile range [IQR]). There was no meaningful correlation between visual acuity and age ($R^2 = 0.0003$; see Fig. 1).

There was a significant age difference between male and female patients (Mann-Whitney $U$ test [MWU], $P = 0.022$), with the men younger (median, 77.5 years) than the women (median, 82.0 years). There was no significant sex-related difference in visual acuity ($P = 0.426$).

Diagnoses showed a wide range from neurologic damage after a stroke to medication toxicity, although most (97/135; 71.8%) had age-related maculopathy (ARM). This subgroup was significantly older than those with other diagnoses (MWU, $P < 0.0001$). Visual acuities in the better eye varied between 20/20 and 20/800 (median 20/139, i.e., approximately 0.15 visus in metric notation). There was no significant difference in visual acuity between ARM patients and those with other diagnoses (MWU, $P = 0.567$).

The control group consisted of 30 healthy subjects from 19 to 84 years of age (15 women) with best corrected visual acuities between 20/20 and 20/40.

The experiments were in compliance with the tenets of the Declaration of Helsinki and were approved by the local Institutional Review Board.

**Stimuli**

Targets were Landolt rings with a gap in one of four possible orientations (right, left, top, and bottom). The target duration was always identical with the response latency (i.e., the target disappeared when the correct response was entered on the keyboard). Target contrast in the Weber notation ($C_W = (I_{\text{max}} - I_{\text{min}})/I_{\text{min}}$) was always maximal at 240%.

**Procedure**

Subjects sat comfortably and viewed the test display from a distance of 40 cm wearing their best available optical correction. Viewing was always binocular, so that performance was mediated by the combination of the capabilities of both retinas. We deemed this acceptable, although there was the possibility that some patients might experience a small functional improvement over monocular acuity.26,27

A beep signalled the impending appearance of a new target. The sequence of locations of appearance was randomized and unpredictable. There were 32 such locations, which were arranged (8 each) on four circles of 2°, 4°, 6°, and 8° eccentricity. Each location of appearance was used only once, so that a trial block had 32 individual trials. The subjects used a ring of 12 mm diameter (1.72°) with a center hole of 2 mm (0.29°) in the middle of the screen as a reference point by initially centering their gaze on it casually. The ring always disappeared before a target appeared.

Subjects were encouraged to use their fovea or preferred retinal locus to make any eye movements they needed to identify the target as quickly as possible. As the controlling software accepted only correct responses, recorded latencies lasted from the target appearance to the correct identification. The subject communicated the response verbally, and the examiner entered it via the computer keyboard. This indirect performance measure was deemed acceptable because it prevented contaminating the data by other variables based on individual differences in age, sex, and educational status.28–30 Instead, each recorded response latency contained a component added by the examiners’ reaction times. Their medians were calculated after 200 trials for each examiner to be 633 ms (DCF) and 603 (MM). For this purpose, we used custom software that generated a randomized sequence of voice recordings of the words “up,” “down,” “left,” and “right” and required a correct response by the examiner via arrow key, as in the regular test.

In each subject, we first determined the visual acuity threshold; the program displayed a series of Landolt rings one at a time, beginning with the largest size and declining in 1/10 log steps. The patient was asked to tell the gap position for each trial. The smallest that could be identified was taken as the size threshold. This size was then doubled and used throughout the entire experiment. Thresholding typically took less than one minute.

**Additional Vision Tests**

All patients were examined by a standardized battery of clinically relevant vision-related tests. These were a detailed functional visual examination by questionnaire, measurement of visual acuity at 1 meter viewing distance, the MNread reading acuity chart,31 a psychological profile by questionnaire, and either microperimetry by SLO or a variant of the tangent screen test to explore scotomatous areas within the central 15° of the visual field (California Central Visual Field Test; Mattingly Low Vision; see http://www.martinglylowvision.com/).

**Experimental Software and Statistical Analysis**

The experimental software ran on an unmodified PC-compatible computer (under Windows ME). The program was custom-written (in Delphi 6; Borland, Inc., Austin, TX). The database attached to the program saved all single trial data, so that they could later be retrieved if necessary.

For statistical analysis, we transferred the data to commercially available software (StatView; Abacus Software, Inc., Berkeley, CA) and used nonparametric statistics to avoid assumptions regarding a normal distribution of the data. Relationships between variables were expressed as coefficient of determination $R^2$. Because it is reasonable to assume a correlation between acuity and reading speed, we also performed multiple regression analysis to gain a more realistic estimate of the contribution of each variable while adjusting for the others. This procedure followed the strategy described by Legge et al.32 We used additional software (SPSS; IBM, Chicago, IL) to regress median latency on reading speed, age, and acuity simultaneously. In addition, logarithmic fitting was also performed.
mic transformations were used on all variables to reduce significant positively skewed distributions. Values of $R^2$ given here are all based on the log-transformed data.

**Test-Retest Reliability**

We examined whether variations of performance between patients might be caused by poor test-retest reliability. Twenty patients and 20 control subjects performed the test twice within a few minutes. Note that calculating the correlations between individual trials of two test runs is not appropriate here, because the sequence of locations of target appearance was randomized. Hence, any trial #M in test run 1 might not be comparable with trial #M in test run 2 in the same patient, because the two trials would most likely have started with target appearances in different locations. The point is exacerbated by the functional heterogeneity of the retinas of our patients due to scotomas and other topographic deficits.

Instead, we used the sums of latencies for each block of 32 trials and subject. The correlation coefficient $R$ served as a traditional measure of test-retest reliability. In addition, we derived the coefficient of determination $R^2$ to indicate what percentage of the variation was accounted for just by repeating the test. The coefficient of repeatability33,34 was calculated as 1.96 multiplied by the SD of the mean differences between the two sets of data.

**RESULTS**

As expected, the test was more difficult for the patients than for a control group of 30 normally sighted subjects of comparable age. This was reflected in the overall duration of the test (mean of 140.0 vs. 87.1 seconds), a higher variability (maximum/minimum response latency ratio of 6.3 vs. 3.4) and a longer median latency (2.521 vs. 1.486 seconds).

**Test-Retest Reliability**

In normal subjects, the correlation coefficient $R$ for the sum of all latencies was 0.92, and the value for $R^2$ was 0.857 (85.7%). The coefficient of repeatability was 6.3% of the average.

In patients, this correlation coefficient was 0.976 and the coefficient of determination $R^2$ was 0.952. The coefficient of repeatability was 12.2% of the average.

**Reading Speed**

Reading could be tested in only 128 of 135 patients because seven either had insufficient reading skills in English ($n = 6$) or stroke-induced aphasia ($n = 1$). We derived best reading speed from the shortest time taken at any size for a 60-character paragraph of MNread text. Reading speeds showed no sex-related differences. Reading speed declined only slightly under the influence of age ($R^2 = 0.0538$; see Fig. 2A). Best speed at any size varied between 45 and 2118 characters per minute (CPM; median, 699 CPM; IQR, 714 CPM). Taking the average word length of 4.05 characters per word in MNread, the median reading speed was equivalent to 172 words per minute.

**Reading with a Scotoma**

Because of the heterogeneity of the patient group regarding the underlying pathology, one could suspect that the measured effects might vary as a function of diagnosis. As the most frequent diagnosis in this cohort was ARM, we looked for the same relationships as above considering only the 97 patients with ARM. We found the results to be very similar to the ones from the whole group (i.e., $R^2 = 0.0335$ for best reading speed versus age; see Fig. 2B).

Although it would not be surprising to see an influence of visual acuity on MNread reading speed in ARM patients, we found this influence to be only moderate ($R^2 = 0.328$; see Fig. 3).

It is important to note that both acuity and age together can make significant independent contributions to reading speed. We found this to be evident from a separate course of multiple regression analysis, in which the latencies from the search paradigm were not included. It yielded $N^2 = 0.4515$, so that 45.15% of the variance of reading speed was accounted for (see also Correlations).

**FIGURE 2.** (A) MNread reading speed declined only moderately under the influence of age ($R^2 = 0.054$). (B) In the subgroup of 97 patients with ARM, there was no meaningful dependence of reading speed on age ($R^2 = 0.033$).

**FIGURE 3.** Visual acuity influenced MNread reading speed only in a moderate way ($R^2 = 0.328$).
Test Duration

It took the patients between 55 and 478 seconds to complete all 32 trials of the Macular Search test (median, 122 seconds; IQR, 82.5 seconds; i.e., typically between 2 and 3 minutes). This test duration showed no appreciable correlation with patients’ age ($R^2 = 0.048$). Men were slightly faster (median duration, 105.5 ± 74 seconds IQR) than women (median duration, 133 ± 77.7 seconds IQR). The difference was statistically significant (MWU, $P = 0.025$).

Test Performance

The most conspicuous result of the “search and identify” paradigm was how much performance levels varied between patients. We measured this by the median latencies of correct responses, which lay between 730 ms and 10,195 ms (a factor of almost 14). The effect was equally drastic when measured by the sum of all 32 latencies per trial block, which varied between 24.4 and 404.0 seconds (a factor of >16).

The sex differences seen in the overall duration showed here too: men performed slightly better (median latency, 2410 ± 1640 seconds IQR) than women (median latency, 133 ± 1650 seconds IQR). The difference was statistically significant (MWU, $P = 0.044$).

In any one patient, latencies varied strongly: the longest latency could be between 1.4 and 31 times longer than the shortest, depending on where the target first appeared. There was a statistically significant performance difference between the subgroups ARM versus non-ARM with the latter being slightly faster (median latency 1730 vs. 2500 ms [MWU, $P = 0.018$]).

Correlations

Because age and visual acuity varied greatly between patients, we investigated possible correlations with the performance level. For median latency versus age, $R^2 = 0.0967$ (see Fig. 4) and for median latency versus visual acuity, $R^2 = 0.176$ (see Fig. 5). This means that only a small part (0.0967 + 0.176 = 0.273 = 27.3%) of the variance of the dependent variable (performance) could be accounted for by the two independent variables age and visual acuity. As both were essentially independent of each other ($R^2 = 0.003$), these two variables could not be interpreted as major influences on search performance. However, we found that the highest correlation between search performance (median latency) and any other variable was the one with best achievable reading speed. Note that these data included several extreme outliers, so that we performed a 10% winsorization. Thus, all values of median latency below the fifth and all above the 95th percentile were set to the fifth and 95th percentile level. The result yielded $R = 0.748$ and $R^2 = 0.560$ (see Fig. 6).

Multiple regression analysis was performed using log median latency as the dependent variable, and age, acuity, and log best possible reading speed (MNR/Speed) as independent variables. Only reading speed was a significant predictor of median latency ($F_{(3,124)} = 55.32, P < 0.001$). Table 1 presents correlation coefficients for the variables, along with the results of the regression analysis. The results tell us that, when all three variables are included in the model, the contributions of age and acuity are not statistically significant. We conclude that the dominating correlation is the one between search performance and best possible reading speed.

Response Latency and Scotoma Size

We examined the potential effect of scotomas of different sizes on search latencies. We had topographic data for 105 of 135 patients from binocular tangent screen tests. We could not use findings from scanning laser ophthalmoscopy for comparisons with data from the macular search test, because the SLO works only monocularly. Due to the limited resolution of the tangent screen test, this can only be considered an approximation. To create clear conditions, we chose 10 patients (ages 18–93 years) with no scotoma. In these cases, the target never ap-

![Figure 4](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933248/)  
**Figure 4.** Search performance was not significantly influenced by patient age ($R^2 = 0.097$).

![Figure 6](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933248/)  
**Figure 6.** MNread best possible reading speed yielded the highest correlation with search median latency (adjusted $R^2 = 0.560$, resulting from multiple regression analysis; see Table 1). The data shown here were winsorized at the fifth and 95th percentile to yield a more robust statistic without data loss.
ears in a scotoma, which should allow instant target localization and, thus, quick responses. We found the mean of the sum of all latencies to be $37.82 \pm 4.86$ seconds.

Conversely, we chose 10 patients (ages 50–96 years) with large scotomatous areas (e.g., through a ring scotoma, or constricted visual fields). Here, the target often appears in a scotoma, which necessitates multiple eye movements. This should cause delayed target localization and, thus, overall longer latencies. We found that their mean of the sum of all latencies was $177.30 \pm 62.34$ seconds.

We calculated the mean over all sums of latencies for all 135 patients as 101.92 $\pm 64.92$ seconds. In the 10 patients with large scotomas, the mean of the sums of latencies was $177.30 \pm 62.34$ seconds. In those 10 with no scotoma, the same value was much shorter: $37.82 \pm 4.86$ seconds.

We tentatively conclude that larger scotomas are more likely to cause longer latencies than small ones. Thus, going from the average to data from patients with a large scotoma increases the latency by a factor of 1.75. Going from the average to data from patients with no scotoma decreases the latency by a factor of 0.37.

**DISCUSSION**

The test-retest reliability for both subject groups turned out to be very good. Regarding the coefficient of repeatability (CoR), it is no surprise that the value for the patients (CoR = 12.2%) was higher than that for the normal subjects (CoR = 8.7%), given the high variability between patients based on their fundamental differences in the topography of vision loss and different diagnoses (12 of 20 had ARM, the others glaucoma, retinitis pigmentosa, diabetic retinopathy, etc.). As the calculation of the CoR uses the SD of the mean differences of latency, which is naturally high for the patients, the value is driven up. Hence, we conclude that in these cases, the conventional pairwise correlation coefficient is the most appropriate measure of test-retest reliability, which was excellent.

The most important finding of the reported research is that search test performance varied greatly despite the fact that visual acuity was neutralized by relating the acuity demand to the individual thresholds. Furthermore, it was surprising to see that the major correlations were essentially the same for the complete cohort with a wide range of diagnoses and for the subgroup with ARM. An additional finding of interest was the fact that the age of the patients did not seem to significantly influence performance. Taken together, all three points support the notion that “search and identify” performance is influenced by factors other than age, visual acuity, and diagnosis. In connection with the points regarding test-retest reliability (see above), we conclude that the found variations between patients are truly patient characteristics and not an effect of poor test-retest reliability.

It is not surprising that some of the patients could read with acceptable speed even with a dense central scotoma in both eyes, which has also been found by others.\textsuperscript{55–58} Note that the current results do not allow direct conclusions from the results of detailed microperimetry by SLO, because the latter can only be performed monocularly. Because reading is a learned behavior, it cannot be ruled out that the found differences might have been influenced by interindividual differences either before onset of low vision, like educational status, or those including low vision, like current reading habits. This indicates that maintaining some reading practice, albeit with adequate magnification, may still pay off for patients with low vision.

Lott et al.\textsuperscript{39} found that good high-contrast acuity does not assure that elderly subjects (58–102 years) can read satisfactorily and that age alone is not a good predictor of reading performance. Thus, one could have expected that our results may come out differently because of the wider age range of our patients (18–98 years) and of their universally compromised vision. However, our results showed the same (i.e., age alone was not a good predictor of reading performance). This can tentatively be explained by the fact that the presence of low vision in our cohort may have simulated the compromising conditions that led Lott and colleagues to their conclusion (i.e., low contrast vision, motor ability, and attentional field integrity).

A recent investigation relating visual capabilities and cognitive status to real-life tasks has shown that performing well in some tasks puts more emphasis on normal functioning in the cognitive domain.\textsuperscript{40} Although we did not formally test for cognitive status here, the psychological profile taken from all patients in this study made sure that no patients with conspicuous cognitive deficits were included. Thus, it is unlikely that deficits in cognitive abilities may have emerged as a major factor.

The presented findings show that measuring visual acuity alone in patients with low vision could have led to entirely misleading conclusions. They demonstrate that there are other factors that influence performance in a task that bears resemblance with those that have to be faced daily by patients with low vision.

**CONCLUSIONS**

Eye movements were allowed in the search paradigm as well as in the reading task, but we did not monitor them in these experiments. We conclude that continuous text reading and the “search-and-identify” paradigms share an important behavioral mechanism that determines performance in both tasks.

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**TABLE 1.** Correlation Coefficients and Standard Multiple Regression of Age, Acuity, and Log MNR-Speed (Best Achievable Reading Speed Using the MNread Test) on Log Median Latency

<table>
<thead>
<tr>
<th>Variables</th>
<th>Log Median Latency (DV)</th>
<th>Age</th>
<th>Acuity (20/)</th>
<th>B</th>
<th>Beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.32*</td>
<td></td>
<td>0.001†</td>
<td>0.097</td>
<td></td>
</tr>
<tr>
<td>Acuity (20/)</td>
<td>0.38*</td>
<td>0.05†</td>
<td>-0.01†</td>
<td>-0.05</td>
<td></td>
</tr>
<tr>
<td>Log MNR-speed</td>
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<td>-0.34*</td>
<td>-0.56*</td>
<td>-0.746</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td></td>
<td>4.40</td>
<td></td>
<td></td>
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<tr>
<td>$R^2$</td>
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</tbody>
</table>

* $P < 0.001$.
† $P > 0.10$. 

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We hypothesize that the factor enabling patients to perform well in both paradigms is oculomotor control and/or eye movement strategy.

It could be argued that the high correlation of the current results with reading performance indicates that a conventional reading test can yield the same results. However, the “find-and-identify” paradigm has four distinct advantages relative to reading:

1. It is independent of the ability to read, so that very young and illiterate patients can also be tested.
2. In patients who can read, differences between levels of reading skill and habits introduce a source of noise into the data that can be avoided in the search paradigm.
3. As long as patient and examiner can communicate verbally, this method allows comparisons between patient cohorts who speak different languages.
4. It demonstrates the spatial position of where goal-directed training could intervene, so that patients could be trained to direct exploratory and compensatory movements in those directions, in which the latencies are found to be longest.9,10

Because steady fixation is not required, the “search-and-identify” paradigm allows functionally relevant vision testing in a relaxed atmosphere and at a wide range of ages, acuities, and reading skill levels.

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References


