Validation of Physiologic Predictors of Successful Telescopic Spectacle Use in Low Vision

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A group of 32 patients with low vision who were considered clinically appropriate candidates for visual rehabilitation with telescopic spectacles were prospectively studied before the first attempted use of these visual aids. Laboratory measurements were made of: (1) rotational head stability in pitch and yaw during quiet standing; (2) sensitivity of visual acuity with telescopic spectacles to imposed yaw head motion; and (3) ocular stabilization reflexes during passive, whole-body rotation in the horizontal plane. Predicted likelihood of successful use of telescopic spectacles was prospectively computed for each patient using the measurement of head stability in the pitch axis and the sensitivity of visual acuity with telescopic spectacles to head motion using a previously described statistical method. Patients were then given telescopic spectacles, and functional success was evaluated in the field at least 6 weeks later by independent masked observers. Although corrected visual acuities did not differ in the 24 patients in whom rehabilitation was successful or in the 8 patients in whom it was not, successful patients had statistically significantly less (P < 0.05) angular head instability in pitch and yaw, as well as less impairment of visual acuity with telescopic spectacles during head motion. This finding was confirmed in a more clinically homogeneous subgroup of 16 patients who had low vision due to maculopathy. Gains of the 0.1 Hz horizontal vestibulo-ocular reflex (VOR) and visual-vestibulo-ocular reflex (VVOR) with 4X telescopic spectacles did not differ between patients in whom rehabilitation was successful and those in whom it was not. Follow-up measurements after long-term use of telescopic spectacles by patients in whom rehabilitation was successful showed no significant changes in either head stability or sensitivity of visual acuity with telescopic spectacles to imposed head motion. Rehabilitation outcomes were compared with predictions computed from laboratory measurements. The positive predictive value was 87.5%, whereas the negative predictive value was 37.5%. These prospective findings support the hypothesis that retinal image stabilization during involuntary head movements is an important determinant of successful visual rehabilitation using telescopic spectacles. Invest Ophthalmol Vis Sci 32:2826–2834, 1991

Telescopic spectacles are commonly prescribed for the large population of patients who have significant but subtotal visual loss. Although these patients with low vision are generally believed to benefit from substantial image enlargement, there is a high rate of unsuccessful rehabilitation in patients with low vision to whom telescopic spectacles have been prescribed. It was hypothesized that a major cause of this unsuccessful rehabilitation is retinal image instability produced by involuntary head movements and magnified by the telescopic spectacles. During unaided vision, the vestibulo-ocular reflex (VOR) produces ocular rotations equal and opposite to head rotations, so that images of stationary objects are stable on the retina. When telescopic spectacles are worn, the retinal image motion that would be produced by head motion is increased in proportion to the optical power of the telescope, necessitating quantitatively greater reflex eye movements to achieve image stabilization on the retina. Although some degree of visual enhancement of these eye movements occurs, it generally insufficient to avert instability of images on the retina during head movements. Such retinal image instability can degrade visual acuity with telescopic spectacles, and can evoke motion sickness.

A retrospective study showed that successful use of telescopic spectacles by patients with low vision could be discriminated by a logistic function of only two...
Physiologic variables. These variables were the intensity of spontaneous head movement in the pitch axis and the sensitivity of visual acuity with telescopic spectacles to imposed head motion. In the study, clinical factors such as diagnosis, peripheral field loss, and age were not predictive of success. Although this evidence supports the idea that retinal image stability is important to visual rehabilitation with telescopic spectacles, the evidence is subject to two major criticisms. First, characteristics of the discriminating variables may not be innate but rather may be learned as a result of chronic use of telescopic spectacles, and thus would not be suitable for prospective use in predicting success. Second, the method for discriminating patients in whom rehabilitation was successful from patients in whom it was not has not been validated in a population different from the one for which it was derived.

This study aimed to prospectively evaluate head stability, sensitivity of visual acuity to head motion, and oculor stabilization reflexes in patients with low vision before their first attempts to use telescopic spectacles, and to correlate these factors with ultimate success in visual rehabilitation with the visual aids.

Materials and Methods

This study was conducted prospectively between 1987 and 1989. Individual ophthalmologists and clinics that treat with patients low vision in the Houston metropolitan area, as well as the Texas State Commission for the Blind, were invited to refer patients to the study. Clinical examinations of all patients were performed by one of the authors (FIP). Best corrected acuity was recorded with conventional spectacle corrections, and thus would not be suitable for prospective use in predicting success. Requirements for inclusion in the study were as follows: (1) presence of a stable visual condition leading to best corrected visual acuity of 20/70 or less; (2) absence of previous experience with telescopic spectacles; (3) presence of a clinical indication for telescopic spectacles; and (4) motivation to use telescopic spectacles. Consistent with prior practice, patients with clinically evident spontaneous nystagmus were excluded.

Participants gave written informed consent to a protocol that was approved by the Institutional Review Board for Human Research at the Baylor College of Medicine, Houston, Texas. All subjects consented to release of their medical records and completed a questionnaire and interview concerning their medical and social histories.

The following clinical data were recorded and considered in data analysis: ocular diagnosis, age, sex, clinically significant visual field loss, coexisting major systemic illness, and telescopic spectacle power prescribed. Sixteen patients had clinical conditions primarily manifested as maculopathy, enabling performance of a subanalysis of this more homogeneous group.

Participating patients then underwent a laboratory test battery consisting of measurements of eye movements, spontaneous head movement, and visual acuity with trial telescopic spectacles. This battery included all tests performed during development of the predictive function described previously. The VOR was recorded during imposed head movement in darkness; the VOR was recorded similarly but while the patients viewed illuminated surroundings using telescopic spectacles. Visual acuity was measured binocularly, using 4X telescopic spectacles, at a distance of 4 m, while subjects were seated in a chair mounted on a vertical axis servomotor. Lines of optotypes varied in constant increments of 20% change in visual angle resolvable. Static visual acuity (SVA) was measured with the subject's head stationary against a headrest. Dynamic visual acuity (DVA) was measured during sinusoidal rotations around a vertical axis at 1.0 Hz, with a velocity amplitude of 20°/sec (position amplitude 3.2°). Acuities were expressed as the logarithm of the minimum angle resolvable (logminarc).

Horizontal eye position was recorded by bitemporal, direct current electro-oculography (EOG), with digital sampling and storage as previously described. Calculations of VOR and VVOR gain were automated, as previously described. VOR gain was measured in complete darkness during sinusoidal whole-body rotation in the motorized chair at 0.1 Hz, amplitude 60°/sec. VVOR gain was measured using standard fluorescent room lighting as patients were rotated at 0.1 Hz, amplitude 30°/sec while wearing telescopic spectacles. Alertness was maintained using mental arithmetic and alphabetical listing tasks monitored via an intercom.

After these measurements, patients underwent adaptation training for 15 min during which they viewed, through telescopic spectacles, a video monitor 4 m away while undergoing sinusoidal rotation at 0.2 Hz, velocity amplitude 20°/sec. This period of combined visual-vestibular experience was designed to train patients to stabilize gaze against head movement while wearing telescopic spectacles. After the adaptation period, DVA, VVOR, and VOR measurements were repeated.

Head stability was evaluated after eye movement testing by measuring spontaneous angular head velocity in roll (about an anterio-posterior axis), pitch (about a medio-lateral axis), and yaw (about a vertical axis), using a velocity transducer (Watson Industries, Eau Claire, WI) mounted on a headband. Initial measurements were obtained sequentially in yaw and pitch only by reorienting the transducer; for follow-up measurements, three transducers that were matched...
to the original one were used for simultaneous measurement in all three axes. Patients were instructed to stand still with their eyes closed and their feet together for 50 sec. Data analysis was performed using Fourier spectral techniques described previously.1,9

After the initial laboratory investigations were completed, telescopic spectacles were dispensed, and financial assistance was provided as necessary. Characteristics of the telescopic spectacle, ie, power and configuration, were as clinically prescribed. Laboratory data were not provided to the investigator-clinician. All patients received conventional training in the use of these telescopic spectacles, as well as clinical follow-up examinations.

Functional use of telescopic spectacles was evaluated 42–182 days after delivery of the devices. Evaluations were conducted in the field in each patient's home, work, education, or transportation setting. At least two evaluations were performed by separate field evaluators, masked to the results of laboratory tests, using a standardized checklist that recorded the amount and quality of use of telescopic spectacles for specific tasks. Consistent with the previous study, successful use of telescopic spectacles was defined as any significant, regular use of telescopic spectacles for any task.1 In cases of discrepancies between the two initial evaluations, a third independent evaluation was performed and the outcome was taken as the finding of the majority. Patients who returned their telescopic spectacles before field evaluation were considered to be unsuccessful. Laboratory measurements of SVA, DVA, and head stability were repeated 72–502 days after initial measurements, except in three patients in whom rehabilitation was successful but who were lost to follow-up. For patients in whom rehabilitation was successful, this period included 72–442 days of telescopic spectacle use.

Statistical comparisons between groups were made using student t-tests. Computations of sensitivity, specificity, and predictive value were made according to conventional statistical definitions.10 Analysis of the relative operating characteristic of the predictive function was performed according to the method of Massof and Emmel.11

Results

Clinical Characteristics

Thirty-two patients with low vision completed the study. The significant disorders causing low vision included: maculopathy (in 16 patients), glaucoma (in 3 patients), optic atrophy (in 3 patients), diabetic retinopathy (in 3 patients), ocular trauma (in 3 patients), retinitis pigmentosa (in 2 patients), and complicated uveitis (in two patients). Of patients completing the study, 24 (75%) were successfully making functional use of telescopic spectacles at the end of the evaluation period, and 8 (25%) were not. One of the patients in whom rehabilitation was unsuccessful (12%) had clinically significant visual field loss, compared with four (17%) of the patients in whom rehabilitation was successful. Of the 16 patients with maculopathy, 10 (62.5%) successfully used the spectacles, and 6 (37.5%) did not. Two of the 3 patients with glaucoma were successful with telescopic spectacles, whereas all were successful in the groups with diabetic retinopathy, optic atrophy, ocular trauma, and uveitis. One of the two patients with retinitis pigmentosa successfully used the spectacles. Major systemic illness, sufficient to alter lifestyle, was found in 2 of 8 patients in whom rehabilitation was unsuccessful (25%), and in 5 of 24 patients in whom rehabilitation was successful (21%).

Stable visual function was required as an entry criterion for this study. An additional two patients completed the protocol, but their data were not considered further because they were found in retrospect to have had significant visual deterioration between initial laboratory testing and field evaluation. One patient had progression of macular degeneration with loss of six lines of static visual acuity during the course of the study, whereas the other had progressive glaucoma with loss of more than three lines.

The mean age of patients in whom rehabilitation was successful was 45.8 ± 4.1 yr (mean ± SEM, range 16–75). The mean age of patients in whom rehabilitation was unsuccessful was somewhat greater at 59.0 ± 5.9 yr (range 32–81), but the difference was not significant (P > 0.05, two-tailed).

Mean corrected visual acuity (without telescopes) for patients in whom rehabilitation was successful was 0.82 ± 0.04 logminarc (mean ± SEM, range 0.54–1.24), not significantly different from the mean value of 0.93 ± 0.13 (range 0.63–1.60) for the patients in whom rehabilitation was unsuccessful. These mean acuities are approximately equivalent to a Snellen fraction of 20/150. The mean telescopic spectacle power prescribed to the patients in whom rehabilitation was successful was 4.4 ± 0.1 (mean ± SEM, range 4–6), which was significantly less than the mean power of 5.4 ± 0.6 (range 4–8) prescribed to the patients in whom rehabilitation was unsuccessful (P < 0.05, two-tailed).

After completion of the study protocol, two patients in whom rehabilitation was unsuccessful were refitted with telescopic spectacles of lower power. In one patient, power was reduced from 6X to 2.8X. In the other patient, power was reduced from 5X to 2.2X. Both patients became successful telescopic spectacle users with the revised telescopes, but the patients were classified as unsuccessful spectacle users with the original prescription, and data were not obtained after the revision.
Dynamic Visual Acuity

Data on visual acuities achieved with standard 4X telescopic spectacles of the patients in whom rehabilitation was and was not successful are shown in Table 1. SVA of the two groups was identical at the initial testing performed before dispensing of prescribed telescopic spectacles. Measurements of dynamic visual acuity (DVA) during head motion imposed by the rotatory chair showed that the motion produced reductions in acuity relative to SVA in both groups of patients. Acuity loss was calculated as SVA minus DVA in logminarc units (Table 1). As expected, acuity loss experienced by patients in whom rehabilitation was unsuccessful (equivalent to about three Snellen lines) was greater than the loss experienced by patients in whom rehabilitation was successful (about two lines). The difference between patient groups was statistically significant and indicated a greater sensitivity of visual acuity to head motion in patients in whom rehabilitation was unsuccessful (P < 0.05, one-tailed t-test).

Measurements of SVA and DVA with telescopic spectacles were repeated 72-442 days after telescopic spectacles were dispensed (72-502 days after initial measurements), and are shown in Table 1. These data indicate that mean SVA and DVA did not change significantly for either group (P > 0.05, two-tailed t-test used because no a priori expectation of the direction of change existed). To detect changes that might have been obscured by interindividual variability, intraindividual comparisons were made on data from patients in Table 1 for whom both initial and follow-up measurements were available. For the 21 patients in whom rehabilitation was successful, paired t-tests showed no change in SVA and a small but significant improvement in DVA of 0.07 ± 0.02 logminarc, corresponding to less than 1 Snellen line (P < 0.01, two-tailed). However, for the six patients in whom rehabilitation was unsuccessful, SVA deteriorated significantly by 0.12 ± 0.03 logminarc, corresponding to about 1 Snellen line (P < 0.01, two-tailed), and DVA deteriorated by 0.07 ± 0.05 logminarc, which was not statistically significant (P > 0.1).

Acuity loss due to imposed head motion (SVA–DVA) tended to be smaller at the time of follow-up than at the time of the initial measurement in patients in whom rehabilitation was and was not successful. Nonetheless, t-tests performed on pooled and paired data indicated that the differences were not statistically significant.

We examined the possible effect of peripheral visual field loss on the initial measurement of acuity loss due to imposed head motion. In the five patients with clinically significant peripheral visual field loss, mean acuity loss due to head motion was 0.30 ± 0.07 logminarc (mean ± SEM). In the remaining 27 patients without clinically significant peripheral visual field loss, mean acuity loss due to head motion was 0.20 ± 0.03 logminarc, slightly but not significantly less (P > 0.05). There was no significant effect of principal diagnosis on acuity loss due to imposed head motion (t-tests, P > 0.05).

Head Stability

Data on head stability are shown in Table 2. Three measures of intensity of head motion were computed for each rotational axis: the value of the peak component in the Fourier spectrum, the integral of the amplitude components over the range of 0–25 Hz, and the root mean square (RMS) value. At initial testing, apparatus was available to measure head stability only in the pitch and yaw axes. Because of an equipment failure, initial head stability data were not obtained in one patient on whom rehabilitation was successful. As expected, all measures of the intensity of

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**Table 1.** Visual acuity with ×4 telescopic spectacles in patients with low vision

<table>
<thead>
<tr>
<th>Measurement</th>
<th><strong>Successful</strong></th>
<th></th>
<th><strong>Unsuccessful</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Final</td>
<td>Initial</td>
</tr>
<tr>
<td></td>
<td>n = 24</td>
<td>n = 21</td>
<td>n = 8</td>
</tr>
<tr>
<td></td>
<td>(Mean ± SEM)</td>
<td>(Mean ± SEM)</td>
<td>(Mean ± SEM)</td>
</tr>
<tr>
<td>Static visual acuity (4X)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logminarc</td>
<td>0.32 ± 0.04</td>
<td>0.33 ± 0.05</td>
<td>0.32 ± 0.12</td>
</tr>
<tr>
<td>Snellen*</td>
<td>20/42</td>
<td>20/43</td>
<td>20/42</td>
</tr>
<tr>
<td>Dynamic visual acuity (4X)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logminarc</td>
<td>0.50 ± 0.04</td>
<td>0.45 ± 0.04‡</td>
<td>0.62 ± 0.11</td>
</tr>
<tr>
<td>Snellen*</td>
<td>20/63</td>
<td>20/56‡</td>
<td>20/83</td>
</tr>
<tr>
<td>Acuity loss, moving†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logminarc</td>
<td>−0.19 ± 0.03‡</td>
<td>−0.12 ± 0.02</td>
<td>−0.30 ± 0.07‡</td>
</tr>
<tr>
<td>Snellen lines*</td>
<td>~2‡</td>
<td>~1</td>
<td>~3‡</td>
</tr>
</tbody>
</table>

* Mean Snellen fraction obtained by conversion of mean logminarc values.
† SVA minus DVA.
‡ P < 0.05 for comparison between successful and unsuccessful, one-tailed t-test. SEM, standard error of the mean.
involuntary head movement in these axes were higher in the patients in whom rehabilitation was unsuccessful than in those in whom it was successful. However, this difference was significant only for the amplitude integrals in the pitch and yaw axes (P < 0.05, one-tailed t-test).

The effect of principal cause of visual loss on RMS head velocity was examined for the pitch axis. Multiple t-tests against the mean value of 1.21 ± 0.08°/sec for the group with maculopathy did not show any effect of diagnosis on RMS values.

When testing was repeated 72-442 days after telescopic spectacles were dispensed, instrumentation was available for simultaneous measurement of head movements in three axes. Four patients in whom rehabilitation was successful and two patients in whom rehabilitation was unsuccessful were lost to follow-up. Mean values (Table 2) for the three measures of the intensity of head movement were again generally greater in patients in whom rehabilitation was unsuccessful than in patients in whom it was not, but none of the differences reached statistical significance (P > 0.05). Within groups, t-test comparisons between initial and follow-up values performed on pooled and paired data did not indicate statistically significant differences for any measure of intensity in any axis (P > 0.05, two-tailed test used because there was no a priori expectation of the direction of change).

An evaluation of the frequency spectral characteristics of involuntary head movements was performed in each rotational axis by dividing spectra obtained at initial testing into six contiguous bins of ~2 Hz each starting at the lowest frequency of 0.1 Hz. Frequencies greater than 12 Hz contained no significant amplitude components and were disregarded. This procedure is equivalent to computing the area under the amplitude spectrum curve for these specific increments of frequency, and dividing by the increment in frequency to obtain the average amplitude component for each region of the spectrum. The subdivided spectra for each rotational axis were then averaged across all of the subjects in the groups of patients in whom rehabilitation was successful vs the patients in whom rehabilitation was unsuccessful. At initial testing, transducers were available for testing in the pitch and yaw axes only, and the resulting binned spectra are plotted in Figures 1A and 1B. For each axis, mean component amplitude was a monotonically decreasing function of frequency. For the pitch axis (Fig. 1A), a significant (P < 0.005) difference in amplitude components between the patients in whom rehabilitation was successful and patients in whom it was not was found only in bin 3, corresponding to the frequency range 4–6 Hz. Differences in the two adjacent bins approached but did not achieve statistical significance. For the yaw axis (Fig. 1B), a statistically significant (P < 0.005) difference in amplitude components between the patients in whom rehabilitation was successful and the patients in whom rehabilitation was unsuccessful was found in bin 4, corresponding to the frequency range 6–8 Hz, as well as in bin 6, corresponding to the frequency range 10–12 Hz (one-tailed t-test, P < 0.01).

A similar analysis was performed for the data on head stability obtained after the patients in whom rehabilitation was successful had chronically used telescopic spectacles. Data on head stability in the roll axis were obtained, in addition to pitch and yaw. Mean spectra for all axes showed similar patterns to those in Figures 1A and 1B, with the largest differences between patients in whom rehabilitation was successful and patients in whom rehabilitation was unsuccessful in bins 3 and 4, corresponding to the frequency range of 4–8 Hz.

Table 2. Spontaneous head velocity in patients with low vision

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Successful</th>
<th></th>
<th>Unsuccessful</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Final</td>
<td>Initial</td>
<td>Final</td>
</tr>
<tr>
<td>Roll (degrees/second)</td>
<td>n = 23</td>
<td>n = 20</td>
<td>n = 8</td>
<td>n = 6</td>
</tr>
<tr>
<td>Peak component*</td>
<td>—</td>
<td>0.28 ± 0.02</td>
<td>—</td>
<td>0.27 ± 0.04</td>
</tr>
<tr>
<td>Amplitude integral*</td>
<td>—</td>
<td>1.08 ± 0.04</td>
<td>—</td>
<td>1.14 ± 0.11</td>
</tr>
<tr>
<td>Root mean square*</td>
<td>—</td>
<td>0.72 ± 0.04</td>
<td>—</td>
<td>0.77 ± 0.11</td>
</tr>
<tr>
<td>Pitch (degrees/second)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak component*</td>
<td>0.43 ± 0.03</td>
<td>0.45 ± 0.04</td>
<td>0.48 ± 0.09</td>
<td>0.41 ± 0.07</td>
</tr>
<tr>
<td>Amplitude integral*</td>
<td>1.41 ± 0.08</td>
<td>1.38 ± 0.10</td>
<td>1.72 ± 0.16</td>
<td>1.48 ± 0.18</td>
</tr>
<tr>
<td>Root mean square*</td>
<td>1.08 ± 0.06</td>
<td>1.09 ± 0.08</td>
<td>1.26 ± 0.11</td>
<td>1.13 ± 0.17</td>
</tr>
<tr>
<td>Yaw (degrees/second)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak component*</td>
<td>0.42 ± 0.04</td>
<td>0.36 ± 0.03</td>
<td>0.47 ± 0.09</td>
<td>0.43 ± 0.10</td>
</tr>
<tr>
<td>Amplitude integral*</td>
<td>1.08 ± 0.06</td>
<td>0.97 ± 0.05</td>
<td>1.40 ± 0.28</td>
<td>1.16 ± 0.16</td>
</tr>
<tr>
<td>Root mean square*</td>
<td>0.93 ± 0.06</td>
<td>0.82 ± 0.05</td>
<td>1.12 ± 0.22</td>
<td>0.98 ± 0.18</td>
</tr>
</tbody>
</table>

* Mean ± SEM.  
† P < 0.05, one-tailed t-test.
Ocular Stabilization Reflexes

Initial VOR and VVOR gains were measured during passive rotation at 0.1 Hz in the horizontal plane (yaw) before the 15-min adaptation period to telescopic spectacles. The mean preadaptation VOR gain for the patients in whom rehabilitation was successful was 0.82 ± 0.05, not significantly different from the value of 0.84 ± 0.06 for the patients in whom rehabilitation was unsuccessful. The mean initial VVOR gain with 4X telescopes was 1.52 ± 0.13 for patients in whom rehabilitation was successful, virtually the same as the mean value of 1.51 ± 0.15 for the patients in whom rehabilitation was unsuccessful. VOR and VVOR gains at 0.1 Hz were again measured after the 15-min adaptation period to telescopic spectacles. No significant gain changes in either VOR or VVOR gain were seen in either patient group after adaptation.

Predictive Function

The likelihood of successful telescopic spectacle use was computed prospectively based on measured values of acuity loss due to imposed head motion $x_1$ (in logmin/arc) and RMS head velocity in the pitch axis $x_2$ (in °/sec). The probability of successful telescopic spectacle use is given by the previously derived predictive function:

$$P(\text{success}) = 1 - \left( \frac{e^y}{1 + e^y} \right),$$

where

$$y = -0.846 - 11.01 x_1 + 4.23 x_2.$$

Success was predicted if $P(\text{success}) \geq 0.5$. (Although head stability data were unavailable for one patient in whom rehabilitation was successful, an unequivocal prediction was obtained in this case because of the large acuity loss due to head motion.) Six of the eight patients in whom rehabilitation was unsuccessful were correctly predicted, and 14 of the 24 patients in whom rehabilitation was successful were correctly predicted. Sensitivity of the predictive function is the proportion of patients in whom rehabilitation was successful correctly predicted to succeed; specificity of the prediction is the proportion of patients in whom rehabilitation was unsuccessful correctly predicted to fail. Based on the a priori criterion for predicted success ($P \geq 0.5$), sensitivity was thus 58%, and specificity was 75%. The positive predictive value (number actually successful of those predicted successful/number predicted successful) was 14/16 = 87.5%, and the negative predictive value (number actually unsuccessful of those predicted unsuccessful/number predicted unsuccessful) of 6/16 = 37.5%.

In general, sensitivity and specificity of the predictive function depend on the criterion probability of success chosen. The relative operating characteristic (ROC) curve is a plot of sensitivity against specificity of a test, for all possible values of criterion. Massof and Emmel advocated the use of the area under the ROC curve as a criterion-free, parameter-free, distribution-independent index of the performance of a diagnostic test. Area under the ROC curve, as applied to this study, was equal to the probability of correctly predicting, in a two-alternative, forced-choice (2AFC) decision task, successful or unsuccessful use of telescopic spectacles in a given patient with low vision. The area under this curve is 0.81, equivalent to an 81% probability of correctly predicting success in a 2AFC test for any one patient.

Sensitivity and specificity for the predictive function as applied to these data are seen in Figure 2, which shows that the curves intersect at a criterion value of 0.20. Although this fact could not have been known prospectively, this criterion would have better discriminated patients in whom rehabilitation was successful from patients in whom rehabilitation was unsuccessful. Applying the criterion probability of $P \geq 0.20$, six of the eight patients in whom rehabilita-
tion was unsuccessful (75%) would have been correctly predicted, and 18 of the 24 patients in whom rehabilitation was successful (75%) would have been correctly predicted.

Two patients in whom rehabilitation was successful who were not predicted to succeed were seen in the field to brace their heads against stationary objects during the use of telescopic spectacles. This strategy diminishes head motion, making the laboratory measurements of head instability unrepresentative of the natural situation for these patients.

Subanalysis of Patients with Maculopathy

Laboratory measurements of predictive factors were analyzed separately for the 16 patients with maculopathy, a group more clinically homogeneous than those in the overall study. Of patients with maculopathy, six were unsuccessful in the use of telescopic spectacles, whereas ten successfully used them. Mean age was 55 ± 6 yr (mean ± SEM) for patients in whom rehabilitation was unsuccessful, and 53 ± 6 yr for the patients in whom rehabilitation was successful (P > 0.05). Best corrected visual acuity without telescopic spectacles was 0.87 ± 0.11 logminarc in the patients in whom rehabilitation was unsuccessful, and slightly but not significantly better at 0.75 ± 0.04 in the patients in whom rehabilitation was successful (P > 0.05, two-tailed). No patient in either group had clinically significant peripheral visual field loss.

In the maculopathy subgroup, the reduction in acuity with telescopic spectacles during head motion was 0.26 ± 0.06 logminarc in the patients in whom rehabilitation was unsuccessful, marginally greater than the value of 0.18 ± 0.05 for the patients in whom rehabilitation was successful (P > 0.05, two-tailed). The RMS value of spontaneous head velocity in the pitch axis was 1.28 ± 0.14°/sec for the patients in whom rehabilitation was unsuccessful, which was slightly but not significantly greater than the value of 1.17 ± 0.10°/sec for the patients in whom rehabilitation was successful. An ROC curve was constructed for the predictive function above using data from the maculopathy subgroup; area under the curve was 0.65. Four of the six patients in whom rehabilitation was unsuccessful (66%) were correctly predicted, and five of the ten patients in whom rehabilitation was successful (50%) were correctly predicted. Based on the a priori criterion for predicted success (P ≥ 0.5), sensitivity of the predictive function was 50%, and specificity was 66%. The positive predictive value was 71%, and the negative predictive value was 44%. If, as discussed above, a criterion probability of P ≥ 0.2 had been applied for prediction of success, five of the six patients in whom rehabilitation was unsuccessful (83%) would have been correctly predicted, and seven of ten patients in whom rehabilitation was successful (70%) would have been correctly predicted.

Discussion

These prospective data, drawn from a patient base in a large metropolitan area, support the usefulness of DVA and head stability for predicting successful use of telescopic spectacles by patients with low vision. Patients in whom rehabilitation was unsuccessful had greater involuntary head motion during quiet standing, as well as greater sensitivity of visual acuity with telescopes to imposed head motion. No significant changes, by paired or unpaired t-testing, were seen in the head stability of patients in whom rehabilitation was successful after the chronic use of telescopic spectacles. This finding supports the validity of head stability measurement as a predictor of successful visual rehabilitation with telescopic spectacles.

In the earlier retrospective study,1 clinical and demographic characteristics, such as corrected visual acuity, diagnosis, and age were not useful predictors of successful use of telescopic spectacles. The most effective means of predicting successful use of telescopic spectacles appeared to be the function using measurements of acuity loss with telescopic spectacles due to imposed head motion, and head stability in the pitch axis. In this prospective study, neither the clinical cause of visual loss nor the presence of clinically significant peripheral visual field loss had any significant relationship to acuity loss with telescopic spectacles due to imposed head motion. Head stability was also independent of the cause of visual loss. In the subgroup of patients with maculopathy, performance of the predictive function was similar to that in the entire group, although the area under the ROC curve (0.65) was somewhat lower than that for the entire group (0.81). This finding suggests that clinical diagnosis and perhaps patient age may have some role in determining the successful use of telescopic specta-
cles, but subsidiary to factors considered in the predictive function. The predictive method tested here thus has value independent of clinical and demographic factors, and might be further improved with consideration of such factors when their effects are discovered by study of larger numbers of patients. Consistently successful use of telescopic spectacles by the small groups of patients with low vision diabetic retinopathy, optic atrophy, and ocular trauma suggests that these conditions may be particularly favorable for this means of visual rehabilitation.

Although no significant improvement was seen in group mean values of either SVA or DVA of patients in whom rehabilitation was successful after chronic use of telescopic spectacles, paired t-testing suggested that DVA improved modestly. This finding implies a beneficial effect of practice on visual acuity with telescopic spectacles under functional conditions when head motion can occur. Despite observed improvement in DVA with experience, the loss of acuity with telescopic spectacles due to imposed head motion, SVA minus DVA, did not change significantly with experience, and thus also was shown to be a valid measurement for initial prediction of successful use of telescopic spectacles. These findings thus validate the assumption of a previous study that factors predictive of this success are intrinsic to individual patients and are not learned as results of chronic use of telescopic spectacles.

In this study, the SVA of patients in whom rehabilitation was unsuccessful decreased by a small but statistically significant amount on follow-up testing; no similar decrease was seen for the patients in whom rehabilitation was successful. This decrease is unlikely to have had an important effect on the successful use of telescopic spectacles. SVA was not predictive of successful telescopic spectacle use in the retrospective study, and in this study the two patients with the largest decreases in SVA on follow-up testing were in the successful group.

Visual deprivation and even reductions in visual acuity and blindness increase postural sway. Patients with low vision have greater involuntary head movement in space than normally sighted subjects and make less use of vision in reducing head instability than the normally sighted. During attempted quiet standing, this instability is greatest in the pitch axis, where vision is ineffective in reducing involuntary head motion, even when telescopic spectacles are worn. The ineffectiveness of impaired vision in influencing head stability may explain why patients with low vision do not automatically learn to minimize involuntary head motion as they gain experience in the use of telescopic spectacles.

The area under the ROC curve provides a criterion-free measure of the effectiveness of a predictive test, and is equal to the chance of making a correct prediction for any individual patient. In the retrospective study, area under the ROC curve was 0.90, whereas in this study the area was 0.81. In the subgroup of patients with maculopathy, the area was 0.65. Although each area exceeds the value of 0.5 expected when a predictive function performs at the level of pure chance, the predictive function did not perform as well in the prospective validation as it did for the sample from which it was derived. Part of this difference is due to the fact that the predictive function was mathematically optimized in the retrospective sample, and its performance for any other sample would not be expected to be as good. Further, in contrast to the equal representation of the positive and negative outcomes in the sample used for derivation of the predictive function, this sample was heavily biased in favor of successful use of telescopic spectacles. Patients were referred with the expectation of success and probably received a higher than usual level of clinical, emotional, and financial support.

The predictive function used here considered only head stability and sensitivity of visual acuity to head motion. It was derived in a group of patients believed to be motivated to attempt use of telescopic spectacles. Obviously, the degree of motivation may differ from patient to patient, providing an unmeasured variable influencing successful rehabilitation with telescopic spectacles. Another such variable is the age of the patients, which was greater, although not significantly, in those who were unsuccessful. Resolution of these questions will require a larger and more diverse patient sample, perhaps through multi-center cooperation.

As reported for the retrospective study, neither horizontal VOR nor VVOR gains at 0.1 Hz were useful in distinguishing patients with low vision in whom rehabilitation was successful from patients with low vision in whom rehabilitation was unsuccessful. Although this fact would seemingly indicate that ocular stabilization reflexes are not important to the successful use of telescopic spectacles, it must be recognized that horizontal rotation at 0.1 Hz does not fully simulate physiologic head instability. The test frequency of 0.1 Hz was chosen for laboratory feasibility because gains measured using the electro-oculographic technique at higher frequencies have a great deal of variability. Horizontal head rotation was also chosen because of the availability of a rotational stimulator in this plane. However, physiologic head movements during standing typically have peak components in all three rotational axes at frequencies up to 5 Hz, with significant components up to 10 Hz. In this study, significant differences in Fourier spectra between patients in whom rehabilitation was successful and patients in whom it was not were seen in the 4–6 Hz
range for pitch, and in the 6–12 Hz range for yaw. Such natural head movements occur at frequencies substantially above the range of the smooth pursuit visual tracking system, which functions effectively at frequencies below 1.0 Hz. This finding is consistent with the observation here that differences in involuntary head movement between patients in whom rehabilitation was successful and patients in whom it was not were greatest in the range of frequencies between 2 Hz, above which pursuit has become ineffective, to 12 Hz, above which the intensity of head movement is probably too small to be disturbing.

Although not yet well studied, there may be special limitations on the interaction of vertical smooth pursuit with the vertical VOR. Large individual variability was found in the vertical VVOR of normal subjects wearing 4X telescopic spectacles. Although different techniques would be necessary, study of the VOR and VVOR during vertical and horizontal, high-frequency head movements, rather than horizontal, low-frequency movements only, could provide much more valuable information in predicting the successful use of telescopic spectacles.

Clinicians who treat patients with low vision should prescribe telescopic spectacles of the lowest power effective for the task. This recommendation is supported by the finding that mean telescopic spectacle power prescribed to patients in whom rehabilitation was unsuccessful was significantly greater than for patients in whom rehabilitation was successful. Two patients in whom rehabilitation was initially unsuccessful with 6X telescopes later successfully used telescopic spectacles having less magnification. Patients with low vision initially trying telescopic spectacles in the clinic should be encouraged to experience the effects of standing and moving on magnified vision and equilibrium. This finding might facilitate learning of head stabilization strategies that were used by several of the patients in whom rehabilitation was successful in this series and who were otherwise predicted to be unresponsive.

**Key words:** dynamic visual acuity, head stability, low vision, telescopic spectacles, vestibulo-ocular reflex, visual-vestibular interaction

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**References**


