

FIXATION STABILITY MEASUREMENT USING THE MP1 MICROPERIMETER

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Purpose: The Nidek microperimeter (MP1, Nidek Instruments, Italy) is a microperimetry device that also assesses fixation stability. The MP1 does not use the method of quantifying fixation stability by calculating a bivariate contour ellipse area (BCEA). Here we compare the MP1 fixation quantification with the BCEA technique by correlating these values to various parameters of reading known to be related to fixation stability.

Methods: Twenty-five people with age-related macular disease were assessed. Eye position was recorded using the MP1 during a fixation task. Fixation score and central 2° and central 4° values were obtained from the MP1. Bivariate contour ellipse area values were calculated from raw fixation data. Reading was assessed using MNREAD, Rapid Serial Visual Presentation, and European reading tests.

Results: Fixation data could not be collected for two observers. For the other 23 participants, the MP1 fixation scores were very poorly related to reading parameters. In contrast, there was a significant relationship between fixation stability assessed using the BCEA technique and Rapid Serial Visual Presentation reading speed ($r = -0.59, P < 0.01$), European reading test reading error rate ($r = 0.66, P < 0.01$), and MNREAD peak reading speed ($r = 0.55, P < 0.05$).

Conclusion: Using the software supplied with the MP1 does not adequately quantify fixation stability in people with age-related macular disease. We recommend that the BCEA technique is used to quantify fixation stability when using the MP1 microperimeter.

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While fixating a point target, the eye is not truly static: fixational eye movements such as drift, microsaccades, and tremor act to keep the retina in motion. In healthy observers using central fixation, the magnitude of these eye movements is small, and all fixations fall within a few minutes of arc of the target center.¹ This ability to maintain steady fixation is impaired in people with eye disease.^{2–6} This deficit in fixation stability is strongly associated with slower reading,⁷ and changes in fixation stability are known to be related to changes in reading speed.⁶

Two approaches have generally been used to measure fixation stability. First, direct observation of the retina can be performed using a confocal scanning laser ophthalmoscope or video fundus camera, and

fixation position can be inferred by the relative position of retinal landmarks and a fixation target on video images² or by computerized tracking of a retinal landmark.⁴ A second method uses an eyetracking system to measure eye motion, after correcting for head movement.⁸ We have shown previously that an infrared gazetracker can be used to measure fixation stability but that fixation is less precise in a “free-head” condition than when the head is restrained with the chin and forehead rest used on the confocal scanning laser ophthalmoscope.⁹

Quantification of fixation stability is usually performed by plotting the position of each fixation on Cartesian axes and calculating the area of an ellipse that encompasses a given percentage of fixations.¹⁰ This bivariate contour ellipse area (BCEA) provides a precise continuous value for fixation stability, with smaller values corresponding to more stable fixation.

The MP1 microperimeter (Nidek Technologies, Padova, Italy) is a recently available clinical instrument that combines an infrared video fundus camera with an LCD display that displays stimuli to the subject. The primary use of the MP1 is to perform retinal-

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specific microperimetry to determine the area and location of vision loss in retinal disease.¹¹ Fixation stability can also be assessed using the MP1, either during a stand-alone fixation test or as part of a conventional microperimetric examination.

The MP1 does not calculate a BCEA to quantify fixation stability. Instead, it follows the example of Fujii et al and classifies fixation as being stable when 75% of fixations fall within a 2° circle; as relatively unstable when 75% of fixations fall within a 4° circle; and as unstable when less than 75% of fixations fall within a 4° circle.¹² This rather arbitrary classification system has recently been criticized by other researchers¹³ and has three significant limitations. First, it does not make allowances for the typical elliptical nature of fixation distribution.¹⁴ Second, this method does not make allowances for the multimodal fixation patterns frequently exhibited by people with macular disease.^{15–18} It will not differentiate between a subject who has good fixation within two discrete yet spatially distant retinal loci and one who has genuinely poor fixation. Finally, it discards much useful information. In our experience, the functional difference between a subject where all fixations lie within 0.5° and where 75% of fixations lie within 2° is large.

To determine whether these three limitations affect the utility of fixation stability as an outcome measure, we measured fixation stability using the MP1 microperimeter and analyzed it first by noting the fixation scores generated by the MP1 software, and then by calculating a BCEA using the raw fixation data collected by the microperimeter. We compared these fixation values to performance on a range of reading tests.

Methods

Twenty-five patients were recruited from the Low Vision clinics at Moorfields Eye Hospital for an exploratory study of eccentric viewing training. All subjects had age-related macular disease diagnosed by an ophthalmologist and bilateral central scotomas demonstrated on gaze-specific retinal microperimetry. No participants had concomitant eye disease, diabetes, or any history of neurologic or psychiatric disease. No participants had visually significant cataracts (as defined by an ophthalmologist). All subjects were fluent in English and had completed at least secondary (high school) education.

Microperimetry

The presence of a dense central scotoma in both eyes was confirmed by use of the “macular 10” microperimetry program supplied with the MP1. Briefly, stimuli were presented at 0 dB (the maximum

brightness of the microperimeter, reported¹¹ as being 127 cd/m²) in a pattern of diameter 10°, centered on the fixation location. Dense scotoma was defined as being the absence of any response to at least two neighboring stimulus points.

All subsequent testing was performed on the better eye only, defined as being the eye with the better visual acuity or the eye with the smaller measured scotoma where the visual acuity was equal. The contralateral eye was occluded in all subsequent experiments.

Fixation Measurement

Fixation stability was measured using the Nidek MP1 microperimeter while a white fixation cross of height 3° presented on a dark background on the LCD screen of the microperimeter. The fixation cross was presented at the maximum luminance of the microperimeter. Subjects were asked to look toward the center of the cross and were encouraged to use peripheral retina if needed. Once subjects had located the cross, fixation was measured for a period of 30 seconds. Eye position was recorded by tracking a retinal landmark at 25 Hz throughout the fixation assessment.

Fixation was quantified in four ways. First, the three fixation measures displayed by the MP1 were recorded: the fixation quality score (stable, relatively unstable, or unstable), the percentage of fixations falling within a circle of 2° diameter, and the percentage of fixations falling within a circle of 4° diameter. Finally, fixation stability was quantified by calculating a BCEA encompassing 68% of fixation points on the basis of the fixation data collected by the microperimeter (exported as a .mfd text file). Bivariate contour ellipse area values were calculated in Matlab (Mathworks, Natick, MA) using the formula:

$$BCEA = 2.28\pi\sigma_H\sigma_V(1 - \rho^2)^{1/2}$$

where σ_H and σ_V is the standard deviation of fixation position in the horizontal and vertical meridian, respectively, and ρ is the product-moment correlation of these two components.

Reading Assessment

Reading was assessed using three different tests, presented in counterbalanced order. Subjects wore an appropriate refractive correction for all reading tests and were instructed to read the text presented as quickly as possible without making errors.

The MNREAD chart (Regents of the University of Minnesota, Minneapolis, MN) was used to measure peak reading speed and critical print size (the smallest text size read at the peak reading speed).¹⁹ Subjects

viewed the chart from 25 cm and sentences were revealed, one at a time, by the investigator. The time taken to read each sentence was recorded. Errors were corrected for as suggested in the most recent version of the MNREAD instructions.

Rapid serial visual presentation (RSVP) of text was performed using a system programmed in Matlab using elements of the psychophysics toolbox.^{20,21} Four word sentences were presented, one at a time, in the center of a cathode ray tube monitor with mean luminance of 50 cd/m². The sentences were randomly generated using a validated computer program that can theoretically generate more than 100,000 sentences without repetition.²² x-height of the text was fixed at twice visual acuity size. Sixty sentences were presented and were graded as read correctly or incorrectly by the investigator. Word exposure duration was modulated by a psychometric staircase (QUEST²³). Reading speed was calculated as being the word exposure duration consistent with 82% reading accuracy.

The third text presentation strategy used was the European reading test²⁴ which comprises extended passages of text of 828 to 830 characters (approximately 160 words). For each subject, one of the 10 available passages was selected at random and was presented on a printed card, at a fixed text size of N20 print. Subjects were asked to read this text using their habitual low vision aid and viewing distance. The time taken to read these paragraphs was recorded, as was the number of errors made on this test.

The study conformed to the tenets of the Declaration of Helsinki and informed consent was obtained from all participants.

Results

Participants were aged between 72 and 95 years, with a mean age of 82 years. Best-corrected visual acuity in the test eye ranged between 0.5 and 1.24 logMAR (20/60–20/320). Six were male. None had refractive error of greater than ± 5.00 D spherical equivalent, or astigmatism of more than 4 D. Further data are given in Table 1. Two subjects had significant missing data upon examination of the MP1 data file. The microperimeter failed to track the retinal landmark for more than half of the 750 possible lines of data. These subjects were excluded from further analyses.

Fixation Classification

The MP1 categorized 3 participants as having stable fixation, 10 as having relatively unstable fixation, and 10 as displaying unstable fixation. The mean percentage of fixations within a 2° circle was 35% (95% CI:

Table 1. Diagnosis and Best Corrected Visual Acuity in the Test (Better) Eye for All Participants

Subject	Diagnosis	Best-Corrected Visual Acuity (logMAR)
1	CNVM + A	0.64
2	Geographic atrophy	0.50
3	CNVM + scar	0.50
4	Geographic atrophy	1.00
5	Geographic atrophy	1.00
6	Geographic atrophy	0.50
7	Geographic atrophy	0.72
8	Geographic atrophy	0.64
9	CNVM + scar	1.04
10	Geographic atrophy	0.80
11	CNVM + scar	0.80
12	Geographic atrophy	1.24
13	CNVM + scar	1.04
14	CNVM + A	0.76
15	Geographic atrophy	0.80
16	Geographic atrophy	1.30
17	Geographic atrophy	0.94
18	CNVM + A	1.20
19	Geographic atrophy	0.50
20	Geographic atrophy	1.00
21	Geographic atrophy	1.02
22	CNVM + scar	0.70
23	CNVM + A	0.70
24	Geographic atrophy	0.82
25	CNVM + scar	1.20

CNVM, choroidal neovascular membrane; A, antiangiogenic treatment.

25–46%) and the mean within 4° was 67% (95% CI: 55–80%).

The mean BCEA value was 13,800 minarc² [interquartile range (IQR) 4,450–31,000 minarc²]. Bivariate contour ellipse area values were not normally distributed and so were log transformed for all further analyses. Logarithm of the BCEA (logBCEA) values were normally distributed (Shapiro Wilk test, $W = 0.98$, $P = 0.88$). Patients within each of the MP1 fixation classifications (stable/relatively unstable/unstable) had significantly different BCEA values (Tukey–Kramer Honestly Significantly Difference test, $P < 0.05$), although there was some overlap in BCEA among the three groups (Figure 1).

There was a weak linear relationship between log BCEA and the percentage of fixations within 2° ($r^2 = 0.32$) and 4° ($r^2 = 0.27$).

Reading Assessment

Mean peak reading speed recorded on the MN-READ chart was 108 words/min (SD: 68), with a mean critical print size of 1.23 logMAR (range: 0.60–1.50 logMAR). Reading speed was slower on the RSVP test (mean: 54 words/min; SD: 45) and the EU

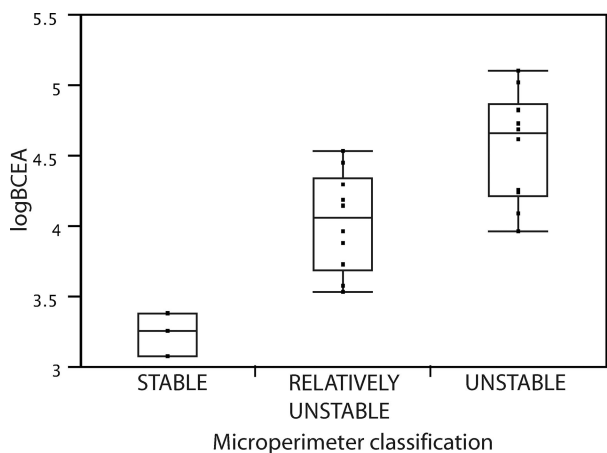


Fig. 1. Relationship between MP1 fixation classification and logBCEA. From bottom to top, horizontal lines represent the minimum value, 25th centile, median, 75th centile and maximum value.

reading speed test (mean: 51 words/min; SD: 33). Median error rate on the EU test was 12.5% (IQR: 3–30; range: 0–55%).

MNREAD peak reading speed was significantly higher than the extended reading speed measured on the EU test (matched pairs; $P < 0.001$). Reading speed measured using the EU and RSVP tests was similar (matched pairs, mean difference = 5 words/min; $P = 0.52$).

Relationship Between Fixation and Reading Parameters

The relationship between the four measures of fixation and the five measures of reading are given in Table 2 and shown in Figure 2. The MP1 classification is significantly related to RSVP reading speed and MNREAD critical print size only in that people with “stable” fixation have a faster reading speed and a smaller critical print size than those in the other two

groups (“relatively unstable” and “unstable”). It is not related to any other measures of reading performance (Tukey-Kramer Honestly Significant Difference; $P > 0.05$). Neither the percentage of fixation points within 2° or the percentage within 4° are related to any of the reading parameters at the 0.05 significance level. In contrast, the BCEA measure of fixation stability is significantly related to RSVP reading speed and MNREAD critical print size at the 0.05 level, and to MNREAD peak reading speed and European reading test error rate at the $P < 0.01$ level.

Discussion

We have shown that there is a strong relationship between fixation stability measured using the MP1 microperimeter and many parameters of reading ability. However, the strength of this relationship is dependent on quantifying fixation stability by calculating a BCEA. The fixation report performed by the MP1 microperimeter is very poorly related to any parameters of reading.

Although it is not surprising that a less quantized measure of fixation (the BCEA) is better correlated to our outcome measures, we were surprised that there was no statistical relationship between the other measures of fixation and our reading results. Our results suggest that the arbitrary classification of fixation adopted by the manufacturers of the MP1 is not appropriate for the evaluation of fixation stability in people with central retinal disease. This is particularly important for studies where fixation stability is a key outcome measure such as in some surgical intervention trials and for longitudinal assessments of fixation stability, such as in visual rehabilitation studies.

Fixation data are collected by the microperimeter, and exporting these data (as a .mfd file) is straightfor-

Table 2. Relationship Between Fixation Measurements and Reading Tests

	RSVP	EUREAD		MNREAD	
	Reading Speed	Reading Speed	Error Rate	Peak Reading Speed	Critical Print Size
Nidek classification	HSD Stable > others $P < 0.05$	HSD NS	HSD NS	HSD NS	HSD Stable < others $P < 0.05$
Proportion within 2°	$r^2 = 0.05$ $P = 0.38$	$r^2 = 0.003$ $P = 0.83$	$r^2 = 0.003$ $P = 0.83$	$r^2 = 0.03$ $P = 0.5$	$r^2 = 0.003$ $P = 0.5$
Proportion within 4°	$r^2 = 0.006$ $P = 0.78$	$r^2 = 0.014$ $P = 0.67$	$r^2 = 0.022$ $P = 0.59$	$r^2 = 0.01$ $P = 0.71$	$r^2 = 0.004$ $P = 0.83$
BCEA	$r^2 = 0.3$ $P < 0.05$	$r^2 = 0.18$ $P = 0.08$	$r^2 = 0.39$ $P < 0.01$	$r^2 = 0.42$ $P < 0.01$	$r^2 = 0.24$ $P < 0.05$

Light shading highlights, $P < 0.05$; Dark shading highlights, $P < 0.01$.

EUREAD, European reading test; HSD, Tukey-Kramer Honestly Significant Difference test; NS, Not significant at $P < 0.05$.

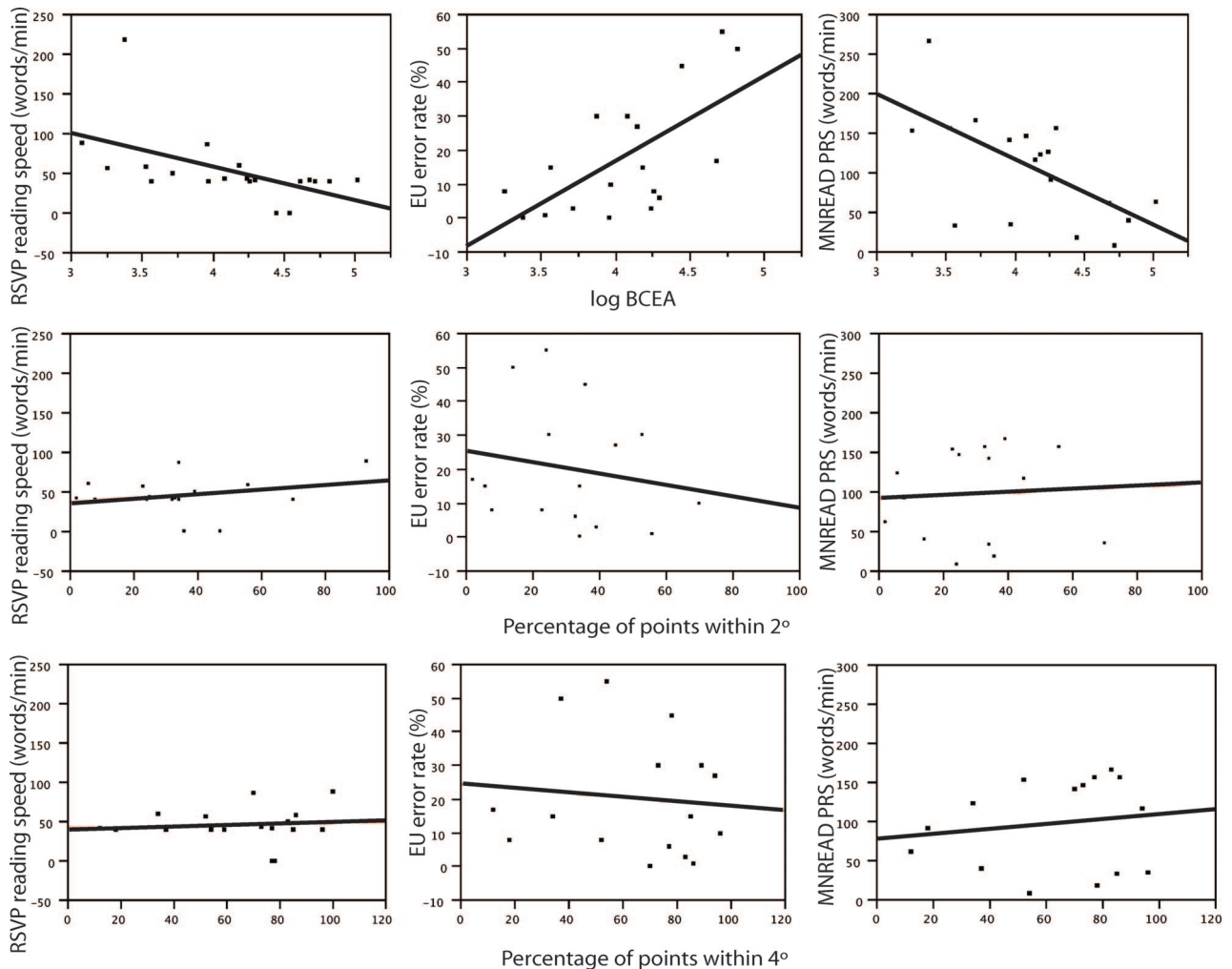


Fig. 2. Relationship between reading parameters and (top) logBCEA values; (middle) the percentage of fixation points falling within 2°; (bottom) the percentage of fixation points falling within 4°. PRS, peak reading speed.

ward. Calculation of the BCEA is also a quick procedure, requiring a few lines of Matlab code, or a formula that can be entered into one cell in Microsoft Excel.

We have not attempted to address the issue of how accurate and repeatable fixation measurements from the MP1 are. Encouragingly, the correlations between our fixation and reading parameters are similar to those that we have previously reported when measuring fixation stability using an infrared eyetracker on a similar cohort of patients.⁶ Using the MP1 classification method, Sawa et al recently reported a significant correlation between fixation stability measured using the MP1 and a confocal Scanning Laser Ophthalmoscope.²⁵

It is noticeable that our patients read more quickly on the MNREAD test than on either the RSVP or magnifier-aided European reading tests. We postulate that this may be because that the MNREAD measures the peak

reading speed at whatever text size the participants read most quickly, selected from several sentences. In contrast, the European reading test and RSVP tests returned only one value for reading speed, due to their fixed text size.

A limitation of measuring fixation behavior on a relatively artificial task like fixating a cross target is that it may not relate well to fixation performance on a more “real-world” task. Fixation is known to be more stable when the head is immobilized, or supported on a chin and forehead rest, compared to when it is unsupported.^{9,26} More significantly, the preferred retinal locus used for fixation is known to differ for different tasks, particularly when luminance is altered.¹⁷ In our study, it would be difficult to claim that fixation properties measured on the MP1 microperimeter would relate to a more natural task, such as reading the European reading test with a stand magnifier. Of course, this limitation relates to the principles of measuring fixation stability with a micrope-

rimeter rather than the method used to quantify fixation. In common with many clinical studies of this type, a further limitation of our study is the relatively small sample size.

The BCEA has become the accepted measure for fixation stability measurement. This technique assumes that fixation positions are unimodal and normally distributed. In common with other groups, we find some departures from normality, but none of our subjects showed any multimodality in their fixation data. Multimodality is a more serious violation of the assumptions underlying the BCEA than small departures from normality. We have previously described a procedure to determine multimodality of fixation data²⁷ and would suggest that in cases of multiple clusters of fixation points, local BCEAs should be calculated for each locus of fixation. Despite these limitations, our results support the use of the BCEA to quantify fixation stability for people with retinal disease, rather than using the classification system built in to the MP1 microperimeter.

Key words: age-related macular disease, fixation stability, microperimetry, reading.

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