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Ludwig-Maximilians-Universitaet Muenchen  
Institut fuer Medizinische Psychologie  
Goethestrasse 31  
80336 Muenchen

Ben.-Gruppe: USER-G  
Tel: 08238-967885  
Mail: eisenbarth.w

Fax:

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Susanne Trauzettel-Klosinski  
Petra Biermann  
Gesa Hahn  
Malte Weismann

## Assessment of parafoveal function in maculopathy: a comparison between the Macular Mapping Test and kinetic Manual Perimetry

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S. Trauzettel-Klosinski (✉) · P. Biermann  
G. Hahn · M. Weismann  
Department of Pathophysiology of Vision  
and Neuro-Ophthalmology,  
University Eye Hospital Tübingen,  
Schleichstr. 12–16, 72076 Tübingen,  
Germany  
e-mail: setrauze@med.uni-tuebingen.de  
Tel.: +49-7071-2984787  
Fax: +49-7071-295164

**Abstract Background:** Parafoveal function is crucial for patients with maculopathies, because they have to use the parafoveal retina for reading after foveal vision loss. Manual perimetry is a reliable but lengthy method for assessing macular function. The Macular Mapping Test (MMTest) was therefore designed as a quick and easy test. In this study both methods were compared in patients with central scotoma. **Methods:** In 50 patients with maculopathy (22 Stargardt's, 20 age-related, 5 diabetic, 3 other macular dystrophies), 30° Tuebingen Manual Perimetry was performed kinetically. The MMTest assesses local responses to brief displays of letters in the central visual field (8° radius) on a computer screen. A "wagon-wheel" pattern is

used to stabilize gaze in the center. Comparison of the methods was based on the correspondence of field defects in each sector. **Results:** The overall correspondence was 87.5%. The results could be divided into three groups, depending on fixation behavior: group 1 ( $n=27$ ): central fixation in both methods, median correspondence 87.5%, best in Stargardt's disease (95.3%), lowest in diabetic maculopathy (71.8%); group 2 ( $n=21$ ): eccentric fixation in both methods (84.3%); group 3 ( $n=2$ ): eccentric in TMP, central in MMTest (65.6% and 81.2%). **Conclusion:** Provided that the fixation locus is known, the MMTest is a quick and easy screening method, which shows a high correspondence with the results of manual perimetry.

### Introduction

Parafoveal function is of utmost importance in patients with maculopathies, because most of them lose foveal vision. To assess macular function, one requires more than visual acuity and the Amsler grid tests. It is necessary to measure visual functions that are relevant for daily living skills, such as reading. Reading problems are the main complaints of patients with maculopathy, and reading performance has been reported to be strongly associated with vision-related quality of life [8, 19].

Reading requires not only sufficient visual acuity, but also a sufficient extent of the retinal area to be stimulated simultaneously during reading [2, 11, 20, 24, 25]. Although conventional perimetry allows parafoveal testing,

many of its automatic variants use insufficient grid sizes so that small scotomas, which can limit reading ability, are not detected.

Another important aspect for reading in patients with maculopathy is their fixation behavior: With an absolute central scotoma, the patient has to use an eccentric retinal area for fixation to regain reading ability. This preferred retinal locus (PRL) becomes the new center of the visual field. Therefore, the scotoma is shifted, together with the blind spot [3, 24, 26]. The blind spot can thus serve as a reference scotoma, and its shift is an indication for eccentric fixation. However, if the location of the blind spot is not determined, the topography of field defects remains ambiguous, so that it is impossible to distinguish between a shifted central scotoma and a para-central scotoma [3, 4, 28].

Therefore, for low vision rehabilitation procedures, it is very helpful to have a perimetric method, which allows the location of the blind spot to be determined. For this purpose, a manual kinetic procedure is specially suited, because the blind spot can be searched. Tübingen Manual Perimetry (TMP) allows a detailed examination of the central 30° of the visual field. The method is specially suited for the examination of low vision patients with central scotoma and has been successfully used in our department for decades [5, 24, 28]. However, it is not available everywhere, requires an experienced perimetrist and is time consuming.

For future clinical trials involving patients with age-related macular degeneration (AMD), the detail and scope provided by conventional perimetry may not always be necessary, while a quick and easy-to-use test of parafoveal function might be all that is needed, not only for early detection of AMD, but also for assessment of treatment effects. Considering the increasing number of AMD patients expected within the next decades [9, 10], new tests for screening and monitoring are needed by ophthalmologists and low vision specialists.

The Macular Mapping Test (MMTest, San Francisco) provides a quick and easy assessment of parafoveal function. It is a computer-based procedure that presents single letters tachistoscopically as recognition stimuli on a common computer monitor (cathode ray tube, CRT) [14, 15]. Like perimetry, it measures visual function topographically, while using letter recognition as a task relating to real-life activities. The test was originally designed to aid the rehabilitation of AMD patients by finding intact macular areas that might be suitable for eccentric viewing, which can be trained [6, 18].

The purpose of this study was to examine whether the MMTest procedure could also be suitable and reliable as a clinical test to measure parafoveal function in patients with maculopathies. To that end, we compared MMTest results with those from Tübingen Manual Perimetry. The first results were reported previously [7].

## Subjects and methods

### Patients

We recruited 50 patients with absolute central scotomas resulting from maculopathies from the Low Vision Clinic Tübingen (mean age: 56±22, range: 17–87 years, 32 females, 18 males). Twenty-two patients had Stargardt's disease (SD), 20 patients had AMD, 5 had diabetic maculopathy (DMP) and 3 had other macular dystrophies (oMDY: 1 cone-rod dystrophy, 1 autosomal dominant drusen, 1 unclassified juvenile maculopathy).

Inclusion criteria were: maculopathy, absolute central scotoma, visual acuity  $\geq 0.05$  ( $\geq 20/400$ ). Exclusion criteria were: reduced physical or mental condition or additional eye disease.

Visual acuity (Snellen) ranged from 0.05 to 0.8 (median: 0.12), median logMAR was 0.9 and the interquartile range 1.2–0.5. (The calculation of the median visual acuity was based on the logMAR values and then reconverted in visual acuity values.)

Magnification requirement ranged from 1–25 times (median 3 times, interquartile range 6.25–2.3, see Table 1). Magnification requirement was assessed by Zeiss Low Vision Reading Charts, which provide sentences in different sizes compared to normal newspaper print (capital letter height 2.0 mm) ranging from 0.8–25 times magnification. It was determined as the smallest print size that could be read fluently with best correction (refraction and presbyopia).

A complete ophthalmological examination was performed on each patient, including morphology of the anterior eye and the retina. The further examination was performed in the eye with better visual acuity, and if equal, in the dominant eye.

All patients gave their informed consent, and the examinations were in accordance to the tenets of the "Declaration of Helsinki."

### Methods

It was not the purpose of this study to align the two methods with each other on the basis of the test conditions, but rather to compare a well-established method with a new test and to define a procedure to compare the results achieved by each method.

#### *Conventional perimetry 30°*

Tübingen Manual Perimetry (TMP) allows high-resolution kinetic examination of the central 30° of the visual field. TMP was performed under standard conditions [5] using a 30-arcmin light spot as a fixation target (320 cd/m<sup>2</sup>) and a background luminance of 3.2 cd/m<sup>2</sup>. The test target (diameter 10 arcmin, 320 cd/m<sup>2</sup> and at least three lower light intensities) was moved with a velocity of 1°–2° per s (Goldmann standard). Special consideration was given to the location and size of the central scotoma and the location of the blind spot. The advantage of a manual procedure compared to an automatic one is the option to examine the regions of interest in more detail. The advantage of TMP compared to Goldmann Perimetry is that the 30° visual field can be examined at an enlarged scale, allowing a detailed search for defects.

Figure 1 shows schematically the shift of the central scotoma and of the blind spot caused by eccentric fixation as assessed by manual perimetry [3, 24, 28].

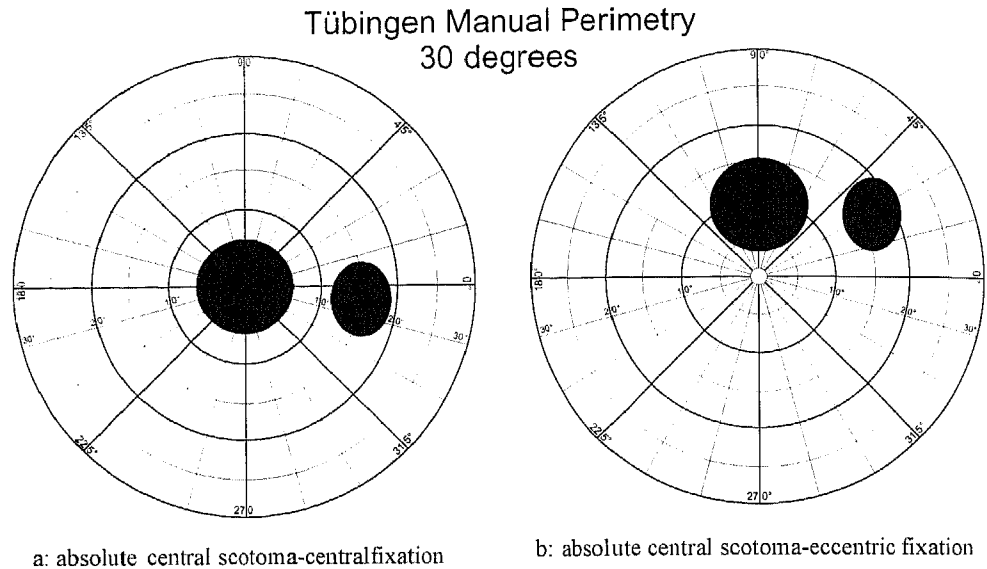
#### *Macular Mapping Test*

A pattern resembling a wagon wheel was used to stabilize the patient's gaze on a computer monitor (Fig. 2a). The viewing distance was 73.2 cm, and the image was calibrated to span 18° diameter of the visual field. In 33 locations, lying at the center and on concentric rings of 2°, 4°, 6° and 8° eccentricity (Fig. 2b), single letters were presented for 250 ms to minimize saccadic eye movements towards the stimulus [1]. All patients were instructed to try to fixate centrally using the wagon wheel pattern as a guide. They were asked: "Can you sense where the center of the circular display is on the computer screen?" and then instructed: "Direct your gaze towards that center and keep it there as still as possible during the test, even if the center disappears" [14]. The examiner determined the letter size by a size adjustment factor according to the patient's visual acuity. In addition, letters were automatically scaled by eccentricity in the visual field [14, 15, 23]. The data were processed by computer, and a topographical map was constructed indicating the locations at which a letter was not detected (black symbol), detected but not recognized (grey symbol) or was correctly identified (white symbol).

### Data analysis

For direct comparison of the results obtained by the two methods, the scales of the graphical printouts were adjusted by enlarging the

**Fig. 1** Assessment of fixation behavior in patients with absolute central scotoma by means of Tübingen Manual Perimetry (30° visual field). **a** In central fixation, the scotoma is located in the center and the blind spot is at its normal location. **b** In eccentric fixation, the scotoma and the blind spot are shifted



**Table 1** Baseline data (diagnoses, sex, visual acuity, log MAR, age, magnification need) and results (groups according to fixation behavior and median correspondence of the test results (TMP versus MMTest) in 50 patients with central scotoma. VA visual acuity (median calculated from logMAR values), median logMAR, 75% and 25% interquartile ranges (IQR), mean age  $\pm$  standard deviation,

MN magnification need (median and IQR), corr correspondence (median and IQR), AMD age-related macular degeneration, SD Stargardt's disease, DMP diabetic maculopathy, oMDY other macular dystrophies. Group 1: central fixation in both methods, group 2: eccentric fixation in both methods, "group 3": eccentric in TMP, central in MMTest

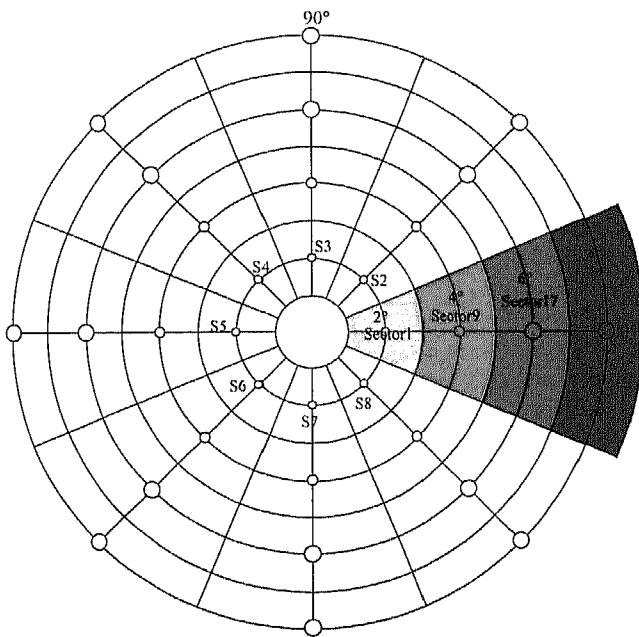
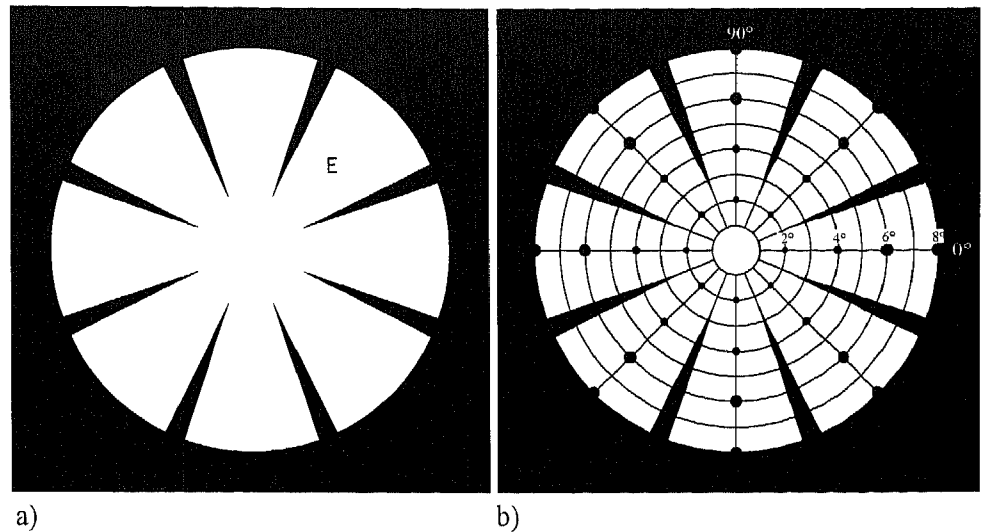
	Total sex		Median VA	Median log MAR	75 and 25% IQR log MAR	Mean age	$\pm$ SD	Median MN	75 and 25% IQR MN	Median corr	75 and 25% IQR corr	
	n	F										M
Total	50	32	18	0.12	0.9	1.2-0.5	56.1	22.5	3	6.25-2.3	87.5	90.6-74.2
AMD	20	18	2	0.2	0.7	1.0-0.4	78	7.5	3	6.1-1.6	87.5	93.8-69.5
SD	22	11	11	0.1	1.0	1.3-0.9	36	12.2	5	6.6-3.0	87.5	90.6-78.1
DMP	5	2	3	0.4	0.4	0.8-0.4	63.2	13	2.5	5.6-1.6	71.8	85.9-67.2
oMDY	3	1	2	0.4	0.4	1.0-0.3	43	11.5	2.5	20-2	87.5	87.5-84.4
Group 1												
Total	27	17	10	0.25	0.6	1.0-0.4	68.7	16.6	2.5	6.0-1.6	87.5	93.8-71.9
AMD	16			0.3	0.55	1.0-0.4	79.1	6.9	2.5	5.6-1.6	87.5	96.1-72.7
SD	4			0.08	1.1	1.3-0.7	49.3	11.5	4.5	20.25-2.6	95.3	99.2-91.4
DMP	5			0.4	0.4	0.8-0.4	63.2	13.0	2.5	5.6-1.6	71.8	85.9-67.2
oMDY	2			0.5, 0.1	0.3, 1.0		38.5	12.05	2.0, 2.5		87.5	
Group 2												
Total	21	13	8	0.1	1.0	1.3-0.9	39	18.5	5	7.1-3	84.3	89.1-76.6
AMD	3			0.12	0.9	1.0-0.7	76.3	12.7	5	6-3	87.5	87.5-59.3
SD	17			0.1	1.0	1.3-1.0	31.6	8.9	5	7.1-3	84.3	90.6-76.6
oMDY	1			0.4	0.4		52		20		84.4	
"Group 3"												
AMD	1	1		0.16	0.8		65		6		65.6	
SD	1	1		0.16	0.78		57		8		81.2	

central 10° of the visual field (TMP) to the size of the MMTest printout. Then the central 10 degrees of the visual field were divided into 32 sectors according to the stimulation grid of the mapping test (see Fig. 3). If more than 50% of a sector was covered by the scotoma, the sector was considered scotomatous. Then the results of the sectors (scotoma: yes/no) were compared with the corresponding test locations of the mapping test (stimulus seen: yes/no). The number of congruent responses was counted, and

the percentage of correspondence between the results of the two methods was calculated for each patient.

To allow a direct comparison of the two methods, we used only the information about "absolute field defects," i.e., from perimetry only the brightest stimulus was evaluated and from the MMTest only the responses "not detected" were counted as deficits. Of course, both methods provide more options (perimetry: thresholds or isopters for different light intensities; MMTest: the option "de-

**Fig. 2** MMTest conditions. **a** fixation target (*wagon wheel*) and stimulus (*E*), **b** test point grid



**Fig. 3** Comparison of TMP and MMTest results. The central 10° of the visual field (*TMP*) are enlarged, adapted to the scale of the MMTest printout and divided into 32 sectors according to the test locations of the MMTest

tected, but not recognized" gives additional valuable information, especially in regard to potential reading ability). It is obvious that we had to undertake a simplification of both tests (detection versus detection) for the direct comparison, instead of using the additive functions.

For describing the subgroups, medians and interquartile ranges (IQR), i.e., the difference between the 25th and 75th percentiles, were calculated.

## Results

### Fixation behavior

Assessed by the location of the blind spot in TMP, 27 patients had central and 23 patients had eccentric fixation during perimetry. When the shape and location of the central scotoma in perimetry was compared to that in the MMTest, 48 patients showed the same pattern of fixation (27 central, 21 eccentric); two patients showed a different pattern: central during MMTest and eccentric during perimetry.

Based on the fixation behavior, the patients were divided into three groups: group 1 ( $n=27$ ): central fixation in TMP and MMTest; group 2 ( $n=21$ ): eccentric fixation in TMP and MMTest and "group 3" ( $n=2$ ): eccentric fixation in TMP and central fixation in the MMTest. (As there were only two patients in this category, we will indicate this group in quotation marks in the following.)

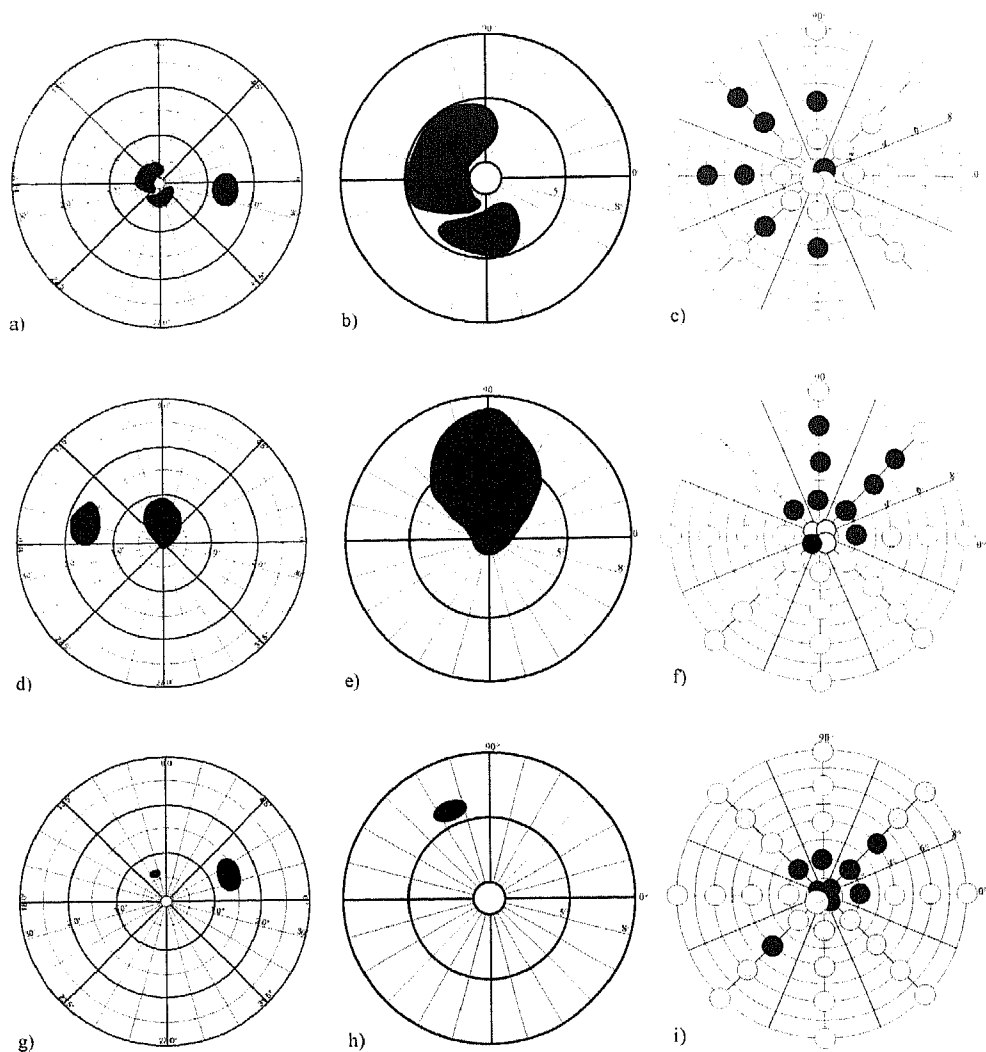
### Correspondence of field defects (TMP versus MMtest)

For the total cohort of 50 patients, the median correspondence was 87.5% (IQR 90.6–74.2).

### Group 1

Twenty-seven patients (16 AMD, 4 SD, 5 DMP, 2 oMDY) had central fixation during both the perimetry and MMTests (Table 1). An example of a patient is given in Fig. 4a–c (at the top). The median correspondence was 87.5% (IQR 93.8–71.9) and varied in the different diagnoses: It was highest in the four patients with SD

**Fig. 4** *Left:* original scale of TMP result ( $30^\circ$ ), including the blind spot; *middle:* enlarged scale of TMP result ( $8^\circ$ ); *right:* MMTTest result ( $8^\circ$ ; *black symbols:* not detected, *grey:* detected, but not recognized; *white:* recognized). *Top (a-c):* patient S (76 years, female, AMD): central fixation in both methods, (blind spot in normal location in **a**), correspondence =75.0%; *middle (d-f):* patient B (28 years, male, SD): eccentric fixation in both methods (blind spot shifted in **d**), correspondence =87.5%; *bottom (g-i):* patient F (57 years, female, SD): eccentric fixation in TMP (blind spot shifted in **g**), central fixation in MMTTest, correspondence =81.2% (after adjusting for different fixation loci)



(95.3%, IQR 99.2–91.4), equal in patients with AMD and oMDY (87.5%, IQR) and lowest in the five patients with DMP (71.8%, IQR 85.9–67.2).

### Group 2

Twenty-one patients (3 AMD, 17 SD, 1 oMDY) showed eccentric fixation in both examinations. Figure 4d–f (middle) illustrates a typical patient example. Median correspondence was 84.3% (IQR 89.1–76.6) without differences between the diagnoses (see Table 1).

### Group 3

Two patients had eccentric fixation in perimetry and central fixation in the MMTTest. After adjusting for the different fixation patterns, they showed a correspondence of

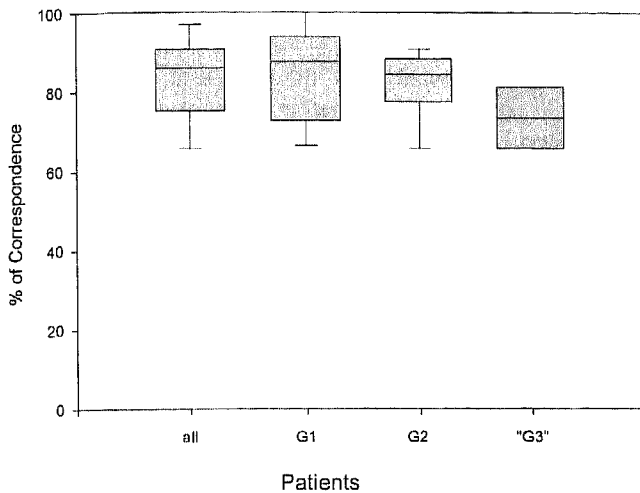
81.3% for the patient with SD and 65.6% for the patient with AMD. Figure 4g–i (bottom) displays the example of the patient with SD.

Figure 5 shows the degree of correspondence dependent on fixation behavior. In “group 3,” only one of the two patients had a low correspondence (65.6%); the other one was located within the IQR of the other groups (81.3%).

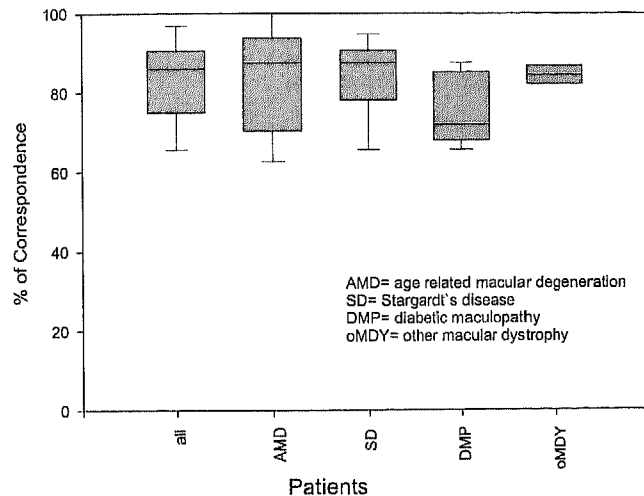
Figure 6 shows the distribution dependent on diagnosis. The patients with DMP show the lowest correspondence (71.8%, IQR 85.9–67.2).

### Examination time

The mean duration of the MMTTest was 4 min 43 s (283 s, range 106–424 s,  $SD \pm 74$  s) for one eye and for the TMP approximately 20 min per eye on average.



**Fig. 5** Degree of correspondence dependent on fixation locus (medians and 10th, 25th, 75th and 90th percentile quantiles). All patients: 87.5%; group 1 (central): 87.5%; group 2 (eccentric) 84.3%; "group 3" (65.6% and 81.2%)



**Fig. 6** Degree of correspondence dependent on diagnosis. The lowest correspondence was obtained in patients with DMP (75.6%); the other diagnoses are very similar (range 82.8–86.5%). See Table 1

## Discussion

Although visual acuity is widely used as a parameter of macular function, it is not a good measure for reading ability, because it measures only one retinal location and does not consider the need for a sufficiently wide reading visual field [2, 11, 16, 17, 27].

Parafoveal function is crucial for reading, and especially important in macular disease. Testing parafoveal vision is therefore important for monitoring the course of a maculopathy or for assessing the effect of treatment and provides a measure of daily living skills.

Amsler grids have been widely used, but they have poor validity and cannot be accurately interpreted for use in the clinical diagnosis of retinal defects—as was shown by a study comparing it with perimetry using a Scanning Laser Ophthalmoscope (SLO) [22]. Conventional perimetry can be a good tool to assess parafoveal function, given that the position of the blind spot as a reference scotoma is determined. The topography of visual field defects can be judged only if the fixation locus is known. Additionally, in an automated grid perimetry, the test point grid has to be dense enough to detect the blind spot. Manual perimetry has the advantage that regions of interest can be examined in more detail, but it requires an experienced perimetrist and can be time consuming.

In a former study where we compared the retinal fixation locus during perimetry with the preferred retinal locus (PRL) in the SLO, we found a high correspondence of 93% in patients with maculopathy and stable eccentric fixation [26]. A discrepancy between the two methods occurred only in those patients who used different PRLs dependent on the size of the fixation target. This shows that the determination of the blind spot in perimetry as a method to assess the fixation locus is quite reliable. Based on this experience, the present study used conventional perimetry as a basis for the comparison with the MMTTest results.

When the size and shape of the visual field defects were compared between the two methods, there was a high degree of correspondence between the results (87.5%). Related to the different diagnoses, the patients with DMP had the lowest correspondence (Fig. 6). The irregular morphology of a DMP can be an unfavorable precondition for stable fixation (central or eccentric). A comparison of the fixation behavior during TMP and MMTTests revealed that 48 of the 50 patients showed the same location of the scotoma (27 central, 21 eccentric). The correspondence varied only slightly between group 1 (87.5%) and group 2 (84.3%), but was reduced in the two patients with alternating PRLs of "group 3" (65.6% and 81.3%). As "group 3" contained only two patients, no conclusions can be drawn.

In group 1 the patients used central fixation during perimetry and MMTTest. However, some of them had a higher magnification requirement indicating an eccentric PRL used for reading [26, 27]. It has to be assumed that these patients had a central visual island within their central scotoma, which allowed central fixation of the TMP target, but was too small for reading [26]. They also still had "the feeling for the center" when they centered their gaze on the wagon wheel in the MMTTest. Patients of group 2 had lost their foveal vision and therefore used an eccentric, established PRL for all targets.

Mackeben and Colenbrander [13, 14] described central fixation of the wagon wheel, whereas in the current group 46% of the patients fixated the wagon wheel target eccentrically. This discrepancy is based on a different

patient selection: They [14] included early stages of AMD without a newly established PRL, whereas we examined more advanced cases with absolute central scotoma, including other macular diseases, using their established PRL for all fixation targets. In relative scotomas, the PRL also depends on lighting conditions [12]. In perimetry, the blind spot can be used as a reference scotoma indicating fixation behavior. This information is lacking in the MMTes, because the test area extends only to 8° eccentricity. Therefore, it cannot be decided if a scotoma is a parafoveal or a shifted central one (compare Fig. 4i). Fixation behavior and visual field topography can be judged only with additional information.

One has to consider that a PRL can be different depending on the size of the stimulus, which is evident in the two patients of "group 3." They fixated the wagon wheel centrally, because they still had the "feeling for the center," but they fixated the fixation target during perimetry eccentrically, indicating a not yet established PRL. This fixation pattern is typical for a transitional stage of maculopathy, as we showed in a former pilot study with SD patients using a SLO [21].

The most exact and reliable measure of a PRL can be done with a SLO, which allows imaging of the fixation locus and the stimulus simultaneously. In 22 of the 50

patients of the current study, we performed a SLO examination, which confirmed the fixation locus assessed by TMP, and it showed also the different PRLs in the "group 3" patients. Other methods can also provide (less quantitative) information on fixation behavior: direct ophthalmoscopy, the observation of the patient's viewing direction and fundus photography [29, 30].

Advantages of the MMTes are that in early stages of maculopathy the fixation can be stabilized in the center of the wagon wheel, because the spikes point to the center, even if the center is not seen by the patient [14, 15]. Another advantage is the short examination time and the easy use, both potentially cost-saving features. The test seems to be suited for early detection of parafoveal visual field defects as well as for monitoring the course of the disease in individual patients, given that fixation behavior can be determined by other procedures.

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