PERGAMON

Vision Research 41 (2001) 2157–2164

Vision Research

www.elsevier.com/locate/visres

Reaction time in automated kinetic perimetry: effects of stimulus luminance, eccentricity, and movement direction

Ulrich Schiefer [a,*], Hans Strasburger [b,1], Stephan T. Becker [a], Reinhard Vonthein [c], Jan Schiller [a], Traugott J. Dietrich [a], William Hart [d]

[a] *Department II, University Eye Hospital, Schleichstrasse 12-16, D-72076 Tübingen, Germany*
[b] *Generation Research Program (Bad Tölz), Humanwissenschaftliches Zentrum (HWZ), Ludwig-Maximilians-Universität, Goethestr. 31, D-80336 München, Germany*
[c] *Department of Medical Biometry, University of Tübingen, Westbahnhofstrasse 55, D-72070 Tübingen, Germany*
[d] *Department of Ophthalmology and Visual Sciences, Washington University School of Medicine, 660 South Euclid Avenue, St. Louis, MO 63110, USA*

Received 22 September 2000; received in revised form 19 February 2001

Abstract

Purpose: To determine the effects of stimulus eccentricity and luminance level on the reaction time (RT) of young normal volunteers during automated kinetic campimetry. Methods: We used a specially designed video-campimetric device equipped with a continuous infrared (IR) pupillographic fixation control (Tübingen Computer Campimeter) and recorded reaction times upon presenting horizontally moving small circular stimuli (size 26′; constant angular velocity 2°/s) starting at 16 locations within the central 30°-radius of the visual field. Two different levels of stimulus luminance were used (41.6 cd/m^2 and 110 cd/m^2), while background luminance was 10 cd/m^2. Each stimulus was presented a total of six times in a randomized order. Subjects were 12 healthy young individuals (aged 21–30 years) with normal ophthalmic examinations. An analysis of variance (ANOVA) was performed on the data. Results: RTs showed considerable inter- and intra-individual variation with individual least squares means (LSM, fitted values of a linear model) ranging from 305 to 454 ms, and residual standard deviation (R.S.D.) 66 ms. Reaction times did not differ significantly as a function of stimulus direction ($P > 0.6$). Higher luminance levels produced significantly reduced reaction times for all stimulus locations and directions (mean reduction: 16 ms; $P < 0.0001$). Reaction times increased with increasing eccentricity, in the mean by 1.8 ms per degree of visual angle, from 365 ± 4 ms (S.E.M.) foveally, to 407 ± 2 ms at 30° eccentricity; ($P < 0.0001$). Conclusions: Automated kinetic perimetry should be designed to cope with significant, variable interindividual response characteristics. Other stimulus related factors, such as eccentricity or luminance level, have a significant but comparatively small effect on reaction time within the central 30°-radius visual field in healthy young individuals.

Keywords: Eccentricity; Psychophysics; Reaction time; Kinetic perimetry; Visual field

1. Introduction

Even though modern automated static perimetry represents a widely applicable method for the clinical assessment of visual field loss, there are situations where neither location nor density of test points seem to be adequate and effective for scotoma evaluation. For instance, patients with hemianopic defects or advanced glaucomatous visual-field loss, have increasing difficulties with the demands made on them by automated static threshold-estimating procedures. Since many stimulus presentations are falling within blind areas of the visual field, much time is consumed needlessly and the patient is frustrated by realizing that he or she is not seeing many of the stimuli. In this context, conventional manual kinetic perimetry can be decidedly more efficient but sets high demands on the examiner's skill. Automation of kinetic perimetric procedures can

* Corresponding author. Tel.: +49-7071-2984786; fax: +49-7071-295038.
E-mail addresses: ulrich.schiefer@uni-tuebingen.de (U. Schiefer), hans.strasburger@lrz.uni-muenchen.de (H. Strasburger).
[1] http://www.lrz.uni-muenchen.de/~Hans_Strasburger/

0042-6989/01/$ - see front matter
PII: S0042-6989(01)00088-8

help to minimize problems related to perimetric technique, but results are still influenced by the patient's ability to respond appropriately to stimulus presentations (Zingirian, Calabria, & Gandolfo, 1979; Gandolfo, Zingirian, & Capris, 1985; Schubart, 1990; Zingirian, Gandolfo, Capris, & Mattioli, 1991; Ballon, Echelman, Shields, & Ollie, 1992; Dietrich, Schiefer, Benda, & Selig, 1997b; Schiefer, Dietrich, & Benda, 1997).

The Tübingen Computer Campimeter (TCC) has been developed to evaluate a variety of perimetric techniques on a fully-calibrated, high-resolution video display unit for stimulus presentation. In contrast to conventional cupola perimeters, this monitor-driven device does not need any mechanical support for stimulus presentation which is especially helpful for realizing kinetic perimetric procedures. The in-house development of software allows the implementation of new procedures and the acquisition of types of perimetric data, like reaction times, that are not obtainable in standard systems. In conventional automated static perimetry, reaction times play no role for detectability result, unless subjects' answers fall outside of a specified time window (Lutz, Dietrich, Benda, Selig, Schiefer, & Daum, 1996, 1997). However, in a kinetic procedure, the measured position of an isopter crucially depends on reaction time, since the movement of a test target continues during the time span between perception and reaction of a tested subject.

This study was designed to address the following questions:

1. To what extent do stimulus eccentricity, luminance levels and other stimulus properties influence the reaction time of normal subjects in automated kinetic perimetry?
2. How relevant are the above-mentioned stimulus-related influences on reaction time compared to subject-related factors?

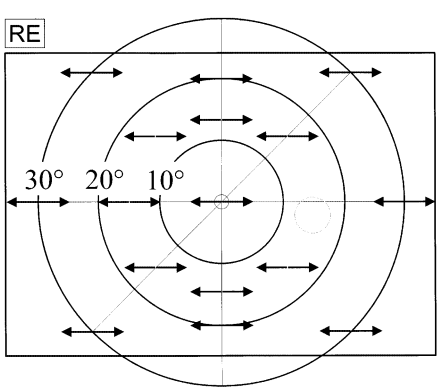

Fig. 1. Locations and directions of the 16 pairs of kinetic stimuli (26′) within the central 30°-radius of the visual field. Movement starting points at 0°, 15°, and 20° or 30°, on the main and oblique meridians, are used. The arrangement is the same for the two eyes, as it is symmetric, but the blind spot is not tested (right eye shown).

2. Methods

2.1. Device

Perimetric examinations for this study were done using programmed procedures implemented in the Tübingen Computer Campimeter (TCC). This device has been described in detail in previous publications (Schiefer & Stercken-Sorrenti, 1993; Wabbels, Schiefer, Treutwein, Benda, & Stercken-Sorrenti, 1995; Schiefer, Stercken-Sorrenti, Dietrich, Friedrich, & Benda, 1996; Schiefer, Benda, Dietrich, Selig, Hofmann, & Schiller, 1999). For this series of experiments the programs were run on a desktop computer which controlled three monitors: kinetic stimuli were displayed on a high-resolution, 20 in. monitor (CALIBRATOR, Barco, Kortriyk, Belgium). Precise control of luminance levels at all screen positions was achieved by an elaborate calibration procedure, based on a photometric acquisition of gamma curves at 48 screen positions, to ensure homogeneity of both background and stimulus luminance values. This technique has been described separately (Dietrich, Selig, Friedrich, Benda, & Schiefer, 1996; Dietrich, Friedrich, Selig, Benda, & Schiefer, 1997a). The maximum and minimum uniform luminance obtainable following calibration were 68 cd/m^2 and 0.2 cd/m^2, respectively. A red, diamond-shaped fixation target was embedded within the colorless (gray) background at the center of the screen. Fixation was monitored through a separate small video system, consisting of an infrared camera that was fixed to the chin- and head-rest, and a small display unit (the second monitor) which allowed the examiner to observe the eye being tested. The images from the camera were sampled every 40 ms by a custom-designed computer graphics board which recorded the pupil's position and horizontal diameter. However, there was no automatic correction for eye movements. The third monitor, a standard 15 in. computer screen, displayed at the start of the measurements the experimental parameters to be used, and during the experiment a pause/continue control window.

2.2. Examination procedure and statistics

Circular-disk stimuli of 26′ diameter were presented, moving slowly, horizontally, at 2 deg/s, within the central 30° radius of the visual field. The target speed was chosen more conservative than the value of 4 deg/s proposed by Johnson and Keltner (1987). The test targets randomly started from one of 16 positions, moving in either rightward or leftward direction. The locations of the stimuli are shown in Fig. 1. With exception of the blind spot, the stimulus arrangement was symmetrical about the vertical axis of the visual field. For the data analysis, data sets for the left eye

were transposed across the vertical axis to match the positions of those for the right eye. The interstimulus interval was varied randomly between 1200 and 1800 ms in order to prevent rhythmic responding. Additionally, invisible stimuli (equiluminant with the background) were randomly presented as catch trials.

Two levels of stimulus luminance were used (41.6 cd/m^2 and 110 cd/m^2); the background luminance was held constant and uniform at 10 cd/m^2. Reaction time (RT) was defined as the interval, in milliseconds, between the onset of a stimulus presentation and the subject's response. Responses were recorded by having the subject press a button. Due to limitations in the implementation under the operating system, reaction-time sampling is not at constant sampling intervals, the latter varying between 20 ms and 27 ms. From the sampling, measured reaction times are biased by half the time of this interval, i.e. by 10–13.5 ms.

One eye was chosen at random for each examination. Rosenbach's method was used to determine whether the chosen eye was dominant (Rosenbach, 1903): the subject occludes a small far-distant object with the thumb; the dominant eye is characterized by an apparent shift of the object or a 'jump of thumb' during alternating lid closure. During the perimetric session, the fellow eye was covered by an opaque occluder. Each stimulus was presented a total of six times, and the order of presentations was spatially randomized among the various stimuli.

Statistical analysis was an analysis of variance (ANOVA) with the factors *luminance*, *eccentricity*, *direction*, *observation number*, and *subject*. The stimulus related factors *luminance*, *eccentricity*, and *direction* were entered as nominal variables. To accommodate for individually differing training and fatigue effects, the effect of *observation number* (centered at 240) was modeled as a second degree polynomial, nested under the factor *subject*. *Subject* was entered as a random factor. To further analyse the influence of stimulus eccentricity, in a second estimation of the above model eccentricity was entered as a continuous explanatory variable. Results are shown as predicted values of the regression (least squares means, LSM) with 95% confidence intervals. A reference interval (confidence interval for a single observation) is given for comparison of inter- and intra-individual variation (Altman, 1991). Interactions were included where indicated by the adjusted coefficient of determination (adj. R^2). Computations were carried out with JMP statistical software, version 3.2.6 (TM of the SAS Institute, Cary, NC, USA, 1999).

2.3. Subjects

Twelve young and healthy individuals with normal ophthalmic findings were recruited for the study. Informed consent was obtained and subjects were given careful instructions prior to starting the examination. The inclusion criteria for the subjects (seven female, five male) were as follows:

- best corrected visual acuity $\geq 20/20$ (each eye);
- best corrected near acuity ≥ 1.0 (Birkhäuser reading text, each eye);
- spherical ametropia $\leq \pm 6$ diopters;
- cylindrical ametropia $\leq \pm 2$ diopters;
- normal stereopsis (all figures correctly read, using the Lang II test);
- no manifest strabismus;
- normal ocular motility with no history of diplopia;
- pupillary isocoria, and no relative afferent pupillary defect;
- IOP of both eyes ≤ 20 mmHg (determined after perimetry by either air pulse or applanation tonometry);
- normal refractive media as assessed with slit lamp and ophthalmoscopy;
- normal fundus in direct ophthalmoscopy;
- brachial blood pressure ≤ 150 mmHg (systolic), and ≤ 90 mmHg (diastolic);
- negative history for ocular or visual abnormalities;
- negative history for neurological disease;
- negative history for hypertension, diabetes and systemic drug use;
- no caffeine, alcohol or nicotine during 2 h before the examination.

3. Results

The mean reaction time over all 4606 observations was 379 ms with a total variance of 75.9 ms^2 (Table 1). Table 2 shows the effect tests and ANOVA for the linear model explaining RT. The largest amount of variance (13%) is accounted for by the factor *subject*, i.e. by interindividual variation, followed by *eccentricity* (6%) and *observation number* (4%). There is further a significant effect of *target luminance* (2%). Direction of movement played no role. $R^2 = 26\%$ of total variance is accounted for by the variables considered here; the R.S.D. is 66 ms.

Even though the overall influence of retinal eccentricity and target luminance are small, they are significant and highly systematic. Reaction times increased significantly with eccentricity in the examined part of the field ($P < 0.0001$). From 0 to 15 deg eccentricity, reaction times increased by 7 ms, and increased more steeply further in the periphery, by 18 ms between 15 and 20 deg and by 16 ms between 20 and 30 deg. Predicted values for different levels of eccentricity and luminance with 95%-confidence intervals are shown in Fig. 2. Reaction time at the *higher* stimulus luminance level (110 cd/m^2) was 349 ± 5 ms in the center of the visual

Table 1
Analysis of variance (ANOVA) of reaction time (RT), tests of the effects of target luminance, subject, observation number, eccentricity, and (horizontal) movement direction

Source of variation	df[a]	Accounted variance (%)	P
Target luminance	1	1	<0.0001
Subject	11	17	<0.0001
No. of stimulus presentation (subject)	12	1	<0.0001
(No. of stimulus presentation)^2 (subject)	12	0	0.0025
Eccentricity	3	5	<0.0001
Direction	1	0	0.66
Error (intraindividual variation)	4565	74	
Total	4605		

[a] df, degrees of freedom.

field, and 391 ± 3 ms for the most peripherally located stimuli at 30 deg eccentricity, a 42 ms increase.

At the *lower* stimulus luminance (41.6 cd/m^2), RT was 365 ± 5 ms at the center of the visual field and increased by 42 ms to 407 ± 3 ms in the periphery. Reaction times were thus slightly but significantly higher (by 16 ms; $P < 0.0001$) at the lower stimulus luminance level compared to the higher one.

Subjects exhibited significant series effects ($P < 0.0001$). RTs rose, in the mean, by 27 ms, from 362 ms for the initial to 389 ms for the last presentation. Such fatigue effect did not outweight a pre- or antecedent training effect in all subjects.

Inter-subject variation exceeded all the systematic variations in this study. Individual LS means range from 305 ms to 454 ms (variance component (37 ms)^2). The R.S.D., i.e. the variance unaccounted for by the above factors, is 66 ms.

4. Discussion

The main findings of our study are a rather high inter-subject variability of reaction times in a reasonably homogeneous group of young, healthy subjects, and a moderate but highly significant increase of reaction time with retinal eccentricity. Linear regression, i.e. entering eccentricity as a continuous regressor in the above linear model, showed RT to increase, between 0 and 30° eccentricity, by 1.8 ms per degree in the mean. According to the first estimation, the increase was shallower within and steeper outside the central 15-deg radius of the visual field. We further found a slight but highly systematic decrease of reaction time with stimulus luminance, 16 ms for two photopic luminances that differed by half a log unit.

Repeated stimulus presentation increased response time in the mean, most presumably due to fatigue, but in some subjects a learning effect was observed. There appears to be no effect of direction of stimulus motion in determining response times, at least for horizontal motion as used in this study. This is in accord with Ball and Sekuler (1979) and Ball and Sekuler (1980), who found no effect for direction of motion on reaction time with their directions tested (60°, 90°, 120°).

When a subject knows that a certain kind of stimulus will occur and is prepared to react quickly without the need for a decision, the time to respond is classified as simple (SRT) as opposed to choice reaction time. The SRT to visual stimuli is, under optimal conditions, around 180 ms (Teichner, 1954; Woodworth and Schlosberg, 1954) and is believed to reflect sensory and motor components only. Modern experimental psychology has mostly turned away from basic sensory pro-

Table 2
Summary of statistics describing how well the model fits the data

Summary of fit	Value
Coefficient of determination R^2	0.258
Adjusted R^2	0.251
R.S.D. (ms)	66
Mean of response (ms)	379
Number of observations	4606

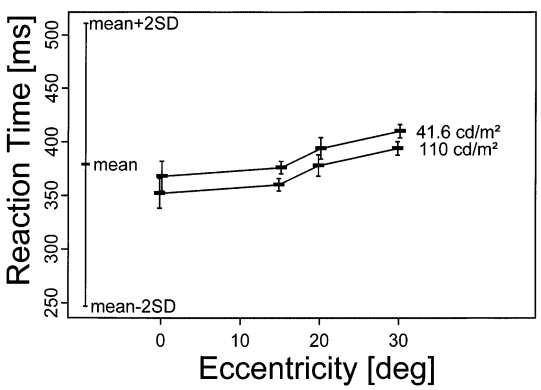

Fig. 2. Mean reaction time (LSM) and 95% confidence intervals by retinal eccentricity, for the two stimulus luminances used. Intra-individual variation is shown on the left for comparison, as a 95%-reference interval centered at the mean of all regressors.

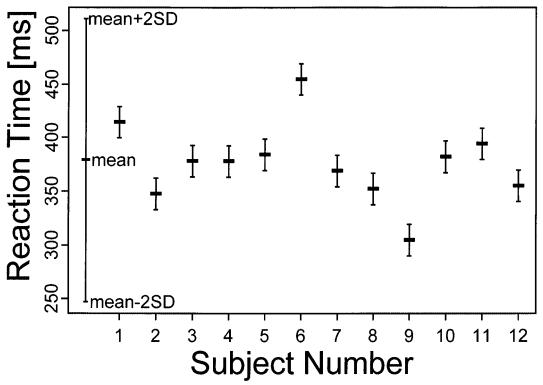

Fig. 3. Intra-individual variation of reaction time (R.S.D. 66 ms), shown as a 95%-reference interval centered at the mean of all regressors, and inter-individual variation of reaction times (variance component $(36ms)^2$) as individual means (LSM 305–454 ms) and 95% confidence intervals.

cesses and there are only few recent studies on the influence of basic stimulus parameters on SRT (Ball & Sekuler, 1980; Tynan & Sekuler, 1982; Kobrick & Sleeper, 1986; van den Berg & van de Grind, 1989). The classical results (e.g. Woodworth & Schlosberg, 1954) thus seem the best yardstick (for reviews see Teichner, 1954; Teichner & Krebs, 1972; Keele, 1986; Luce, 1986).

A number of well-established results are of interest for our study and its application in kinetic campimetry/perimetry. SRTs change little with age between around 15–60 years but there is substantial slowing at younger ages and moderate slowing at older ages with 60 year old subjects still being faster than 10 year olds (Bellis, 1933). The body part with which the response is made has only modest effect upon reaction time, with a heavier part like the upper arm being slightly slower, about 15 ms, than the finger. Binocular viewing results in slightly shorter reaction times than monocular viewing (Ueno, 1977) and the difference seems on the order of 10%.

Information on the dependency of reaction time on retinal eccentricity, which is of particular interest in our study, is overall rather scarce. Poffenberger (1912) already found an increase of reaction time with stimulus eccentricity, with an increase of 24 ms at 45 deg temporally and 15 ms nasally, corresponding to about 0.53 ms/deg in the temporal and 0.33 ms/deg in the nasal visual field (see Teichner, 1954). Rains (1963) reports a slowing in the nasal but not in the temporal visual field of 20 ms at 5 deg eccentricity, i.e. by 5 ms/deg in the perifovea, and a further shallow increase of 10 ms at 30 deg eccentricity (0.4 ms/deg). The nasal slowing is thus, on the average, 1 ms/deg. They find no slowing in the temporal visual field. The overall values of Poffenberger (1912) and Rains (1963) are similar to what we found.

Kobrick and Sleeper (1986) report a rather steep increase of SRT with eccentricity of 20 ms/deg, a much higher value than found in other studies and the 1.8 ms/deg found by us. Their results might, however, unduly exaggerate the influence of eccentricity for a number of reasons. For one, fixation seems not well controlled or otherwise it is unclear how subjects were able to detect stimuli at ± 90 deg on the vertical meridian. Peripheral reaction times thus seem inflated by searching for invisible stimuli. Second, the stimulus duration, luminance of the used LEDs and background luminance are not reported, so that it is difficult to compare results. Third, the text concludes that the increase with eccentricity of reaction time is pronouncedly smaller on the horizontal than on the vertical meridian (which would be expected), whereas the corresponding figure (Fig. 3) shows the contrary. It is thus not clear what the reasons for the deviating findings in Kobrick and Sleeper (1986) are.

Concerning the effect of eccentricity, two findings by Tynan and Sekuler (1982) are of further interest here. Perceived stimulus speed decreases steadily with increasing eccentricity and at 30 deg eccentricity has declined to about half the actual speed. Our most peripheral stimuli will thus appear as moving at about 1 deg/s. Speed threshold, i.e. the lowest speed at which a sudden movement onset is detected, is around 0.03 deg/s foveally and increases steadily with eccentricity, reaching about 0.4 deg/s at 30° eccentricity. At 2 deg/s our stimuli are thus well above threshold including the most eccentric positions.

The influence of stimulus luminance on reaction time has been well studied (see Teichner, 1954 and Teichner & Krebs, 1972, for reviews), and the studies agree that reaction times become shorter with increasing luminance. The slight decrease of reaction time with luminance that we find is in line with these results and indeed with what is to be expected from the classical law of Piéron (1920) or modern variants of it (Teichner & Krebs, 1972).

Visual performance in many if not all measures decreases steadily with increasing eccentricity in the visual field (for reviews see Weymouth, 1958, Pointer, 1986 and Strasburger, Rentschler, & Harvey, 1994 for further references). The increase of reaction time with retinal eccentricity that we find here should be set into this context. The neuronal basis of the effects of eccentricity are found on all levels of the primary, retino–geniculo–cortical pathway. Of particular interest for movement sensitivity is the magno pathway, involving retinal parasol ganglion cells and geniculate magno cells. There is an ongoing debate about whether, in the retina and the lateral geniculate, cells of the magno path are distributed differently from those of the parvo pathway. Current evidence suggests this to be the case for both the retina and the geniculate (Azzopardi &

Cowey, 1996; Azzopardi, Jones, & Cowey, 1999) which means that it is useful to consider movement sensitivity independent of performance with static stimuli.

When linking a performance measure like reaction time to retinal position, a mediating variable is required that provides the link to the underlying spatial cell densities. In the present context this would be stimulus size and a space-based measure of stimulus speed like distance (in degrees of visual angle) traveled by the moving stimulus in a certain time. The M-scaling principle (Rovamo, Virsu, & Näsänen, 1978; Virsu, Näsänen, & Osmoviita, 1987), for example, would predict that scaling stimulus size and speed according to the cortical magnification factor would yield reaction time independent of retinal position. A similar prediction could be based on retinal or on geniculate magno cell densities or on receptive field diameters. Receptive field diameters seem to be roughly 13-fold at 30 deg eccentricity (1.2°) compared to the fovea (0.1°) (Oehler, 1985); a comparable increase of stimulus size and/or speed would then be expected to equalize reaction-time performance. Our stimuli had a diameter of 26′ (i.e. 0.43°) and were thus much larger than the average foveal receptive field, but covered only about 1/4 of the average receptive field at 30 deg eccentricity. Unfortunately, there seems to be no literature data on how reaction time depends upon stimulus size and motion speed in the visual periphery. Future studies might close this gap and could thereby fit the variations of reaction time with eccentricity into a more general framework.

The relative extent of all the above-mentioned systematic effects of stimulus characteristics appears moderate when compared to the inter-individual variance which accounts for 1/5 of total variation. This fact is of major importance in any clinical application, and in particular in kinetic perimetry, where stimulus position depends upon time. Automation of kinetic examination techniques (Zingirian et al., 1979; Gandolfo et al., 1985; Schubart, 1990; Zingirian et al., 1991; Dietrich et al., 1997b; Schiefer et al., 1997) can be used to eliminate examiner bias and to correct for variations in stimulus-related and subject-related variables that affect the measurement of kinetic thresholds.

In automated *static* perimetry, by the very design reaction time does not normally influence the estimation of thresholds (unless the latency of an individual response falls outside a predefined time window). Too short response times indicate subject's anticipation rather than a response. Prolonged reaction times on the other hand may result in artificially increased threshold values (Lutz et al., 1996, 1997). In any case such responses can be easily discarded of in static perimetry. In kinetic perimetry, however, reaction time does have a significant effect on the position of an isopter: Depending on which direction the stimulus is moved — from non-seeing to seeing areas of the visual field or vice versa — the scotoma size will be artifactually enlarged or decreased unless the influence of reaction time is taken into account.

With manual kinetic procedures, a standardized assessment of response latency is not possible and the examiner has to rely on a subjective estimate of patient performance. The variance thus introduced will affect the accuracy and consistency of results. Computer automation of kinetic perimetry is, therefore, desirable, such that quantitative assessment of patient performance can be routinely incorporated into the examination procedure. This is of particular importance when a patient to be tested for a potential lesion of the visual pathways for some reason has impaired vigilance. This may occur, e.g. in cases of advanced age, of a brain lesion or dysfunction, intoxication, several kinds of drugs, or pronounced fatigue. It is of prime importance in such cases to differentiate between the real affection of the visual field and the impact of prolonged reaction time. Since vigilance shows considerable between-session variability, this is of further relevance in follow-up controls, in particular when advanced visual-field defects are present.

A typical example for the clinical relevance of such considerations is the examiner-independent evaluation and follow-up of the natural course of illness, or of the therapeutic efficacy of a treatment, in lesions of the posterior visual pathways; the latter may not only induce homonymous visual-field defect but eventually also impair a patient's vigilance. Another example are tapeto-retinal degenerations resulting in a progressive concentric constriction of the visual field. A special subtype of that kind of visual-field defect has recently been described as resulting from the GABAergic antiepileptic drug Vigabatrin (Wild, Martinez, Reinshagen, & Harding, 1999). Since an increase of response time in seizure patients, especially under antiepileptic treatment, is well-known, an assessment of reaction time seems to be of particular interest in order to differentiate between a true visual loss and an artifactual diagnosis of visual loss from prolonged answer latencies. The results of our study demonstrate that already in the — comparatively homogenous — group of young, healthy volunteers there is a considerable variability of reaction time. It is evident that this variability will be drastically higher in patients and, therefore, needs to be taken into account in meaningful automated kinetic perimetry.

5. Conclusion and outlook

In kinetic perimetry, a number of stimulus-related properties have a sizeable and highly systematic effect upon reaction time. Most noticeably, these are retinal eccentricity — 1.8 ms/deg — and target luminance, and there is further a certain fatigue from the repeated

presentation of moving stimuli. Further on, there is considerable interindividual variation that exceeds the systematic effects. Automated techniques for kinetic perimetry should be designed to take both the systematic and subject-specific effects into account to prevent artifactual dislocation of boundaries of impairment in the visual field. We propose automated kinetic-perimetry procedures to routinely include a rapid method of separately determining a test subject's personal reaction time, and to repeat that procedure at each session to capture changes of vigilance. A method for doing so is to present, in the course of each examination, catch trials in functionally normal areas of the visual field. The location of resulting isopters could thus be automatically corrected for the effects of reaction time in any given subject.

Acknowledgements

The authors thank Bettina Selig for her effort and support during the examinations. Supported by the Tübingen Fortüne program No. 445 and by DFG BR-1689/2-1.

References

Altman, D. G. (1991). *Practical statistics for medical research* (pp. 420–423). London: Chapman and Hall.

Azzopardi, P., & Cowey, A. (1996). The overrepresentation of the fovea and adjacent retina in the striate cortex and dorsal lateral geniculate nucleus of the macaque monkey. *Neuroscience*, *72*, 627–639.

Azzopardi, P., Jones, K. E., & Cowey, A. (1999). Uneven mapping of magnocellular and parvocellular projections from the lateral geniculate nucleus to the striate cortex in the macaque monkey. *Vision Research*, *39*, 2179–2189.

Ball, K., & Sekuler, R. (1979). Masking of motion by broadband and filtered directional noise. *Perception and Psychophysics*, *26*, 206–214.

Ball, K., & Sekuler, R. (1980). Models of stimulus uncertainty in motion perception. *Psychological Review*, *87*, 435–469.

Ballon, B. J., Echelman, D. A., Shields, M. B., & Ollie, A. R. (1992). Peripheral visual testing in glaucoma by automated kinetic perimetry with the Humphrey field analyzer. *Archives of Ophthalmology*, *110*, 1730–1732.

Bellis, C. J. (1933). Reaction time and chronological age. *Proceedings of the Society for Experimental Biology and Medicine*, *30*, 801–803.

Dietrich, T. J., Selig, B., Friedrich, M., Benda, N., & Schiefer, U. (1996). Calibration routines for video display units for perimetric examinations. *German Journal of Ophthalmology*, *5*, 125.

Dietrich, T. J., Friedrich, M., Selig, B., Benda, N., & Schiefer, U. (1997a). Application of video display units for campimetric purposes-luminance characteristics and calibration procedures. In M. Wall, & A. Heijl, *Perimetry update* 1996/1997 (p. 471). Amsterdam: Kugler.

Dietrich, T. J., Schiefer, U., Benda, N., & Selig, B. (1997b). Autokinetische Perimetrie bei Patienten mit Retinitis pigmentosa. *Der Ophthalmologe*, *94*, 141.

Gandolfo, E., Zingirian, M., Capris, P., 1985. The automated program 'genoa glaucoma screening'. In: *Proceedings of the 6th International Visual Field Symposium*, Dordrecht: Junk, pp.103-107.

Johnson, C. A., & Keltner, J. L. (1987). Optimal rates of movement for kinetic perimetry. *Archives of Ophthalmology*, *105*, 73–75.

Keele, S. W. (1986). Motor control. In K. R. Boff, L. Kaufman, & J. P. Thomas, *Handbook of perception and human performance*, *Vol. II*: *cognitive processes and performance*. New York: Wiley.

Kobrick, J. L., & Sleeper, L. A. (1986). Effect of wearing chemical protective clothing in the heat on signal detection over the visual field. *Aviation*, *Space*, *and Environmental Medicine*, *57*, 144–148.

Luce, R. D. (1986). *Response times*. New York: Oxford University Press.

Lutz, S., Dietrich, T. J., Benda, N., Selig, B., Schiefer, U., & Daum, I. (1996). Computer perimetry using different techniques of inquiring answers. *German Journal of Ophthalmology*, *5*, 125.

Lutz, S., Dietrich, T. J., Benda, N., Selig, B., Schiefer, U., & Daum, I. (1997). Two different techniques for obtaining answers in automated perimetry. In M. Wall, & A. Heijl, *Perimetry Update* 1996/1997. Amsterdam: Kugler.

Oehler, R. (1985). Spatial interactions in the rhesus monkey retina: a behavioural study using the Westheimer paradigm. *Experimental Brain Research*, *59*, 217–225.

Piéron, H. (1920). Nouvelles recherches sur l'analyse du temps de latence sensorielle et sur la loi qui relie ce temps a l'intensité de l'excitation. *Anné Psychologique*, *22*, 58–142.

Poffenberger, A. T. (1912). Reaction time to retinal stimulation, with special reference to the time lost in conduction through nerve centers. *Archives of Psychology*, *23*, 1–73.

Pointer, J. S. (1986). The cortical magnification factor and photopic vision. *Biological Reviews of the Cambridge Philosophical Society*, *61*, 97–119.

Rains, J. D. (1963). Signal luminance and position effects in human reaction time. *Vision Research*, *3*, 239–251.

Rosenbach, O. (1903). ber monoculare Vorherrschaft beim binocularen Sehen. *Medizinische Wochenschrift*, *50*, 1290–1292.

Rovamo, J., Virsu, V., & Näsänen, R. (1978). Cortical magnification factor predicts the photopic contrast sensitivity of peripheral vision. *Nature*, *271*, 54–56.

Schiefer, U., & Stercken-Sorrenti, G. (1993). Ein neues Rauschfeldkampimeter. *Klinische Monatsblätter für Augenheilkunde*, *202*, 60–63.

Schiefer, U., Dietrich, T. J., & Benda, N. (1997). Autokinetische Perimetrie/Kampimetrie-Prinzip und Einsatzbeispiele. *Der Ophthalmologe*, *94*, 176.

Schiefer, U., Stercken-Sorrenti, G., Dietrich, T. J., Friedrich, M., & Benda, N. (1996). Fundus-orientierte Perimetrie—Evaluation eines neuen Gesichtsfeld-Untersuchungsverfahren bezüglich der Detektion von Angioskotomen. *Klinische Monatsblätter Jui Augenheilkunde*, *209*, 62–71.

Schiefer, U., Benda, N., Dietrich, T. J., Selig, B., Hofmann, C., & Schiller, J. (1999). Angioscotoma detection with fundus-oriented perimetry. A study with dark and bright stimuli of different sizes. *Vision Research*, *39*, 1897–1909.

Schubart, P. (1990). Kontinuierliche Profil-Perimetrie. *Klinische Monatsblätter Jui Augenheilkunde*, *196*, 94–100.

Strasburger, H., Rentschler, I., & Harvey, L. O. Jr (1994). Cortical magnification theory fails to predict visual recognition. *European Journal of Neuroscience*, *6*, 1583–1588.

Teichner, W. H. (1954). Recent studies on simple reaction time. *Psychological Bulletin*, *51*, 128–149.

Teichner, W. H., & Krebs, M. (1972). Laws of the simple visual reaction time. *Psychological Review*, *79*, 344–358.

Tynan, P. D., & Sekuler, R. (1982). Motion processing in peripheral vision: reaction time and perceived velocity. *Vision Research*, *22*, 61–68.

Ueno, T. (1977). Reaction time as a measure of temporal summation at suprathreshold levels. *Vision Research*, *17*, 227.

van den Berg, A. V., & van de Grind, W. A. (1989). Reaction times to motion onset and motion detection thresholds reflect the properties of bilocal motion detectors. *Vision Research*, *29*, 1261–1266.

Virsu, V., Näsänen, R., & Osmoviita, K. (1987). Cortical magnification and peripheral vision. *Journal of the Optical Society of America A*, *4*, 1568–1578.

Wabbels, B., Schiefer, U., Treutwein, B., Benda, N., & Sterncken-Sorrenti, G. (1995). Automated perimetry with bright and dark stimuli. *German Journal of Ophthalmology*, *4*, 217–221.

Weymouth, F. W. (1958). Visual sensory units and the minimal angle of resolution. *American Journal of Ophthalmology*, *46*, 102–113.

Wild, J. M., Martinez, C., Reinshagen, G., & Harding, G. F. (1999). Characteristics of a unique visual field defect attributed to Vigabatrin. *Epilepsia*, *40*, 1784–1794.

Woodworth, R. S., & Schlosberg, H. (1954). *Experimental Psychology*. New York: Holt.

Zingirian, M., Calabria, G., & Gandolfo, E. (1979). The nasal step in normal and glaucomatous visual fields. *Canadian Journal of Ophthalmology*, *14*, 88–94.

Zingirian, M., Gandolfo, E., Capris, P., & Mattioli, R. (1991). Computerized system for static and kinetic automatic perimetry. *European Journal of Ophthalmology*, *1*, 181–186.