

Factors Influencing Reaction Time during Automated Kinetic Perimetry on the Tübingen Computer Campimeter

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PURPOSE. To determine the effect of age, examination, location, luminance, subject, and vigilance on reaction time (RT) in automated kinetic perimetry.

METHODS. Thirty-six normal volunteers (20–70 years old) underwent kinetic campimetric examinations, during which RTs (time from appearance of a stimulus to response) were recorded. Stimuli with a diameter of 26 minutes of arc (Goldmann III) were presented on horizontal vectors with an angular velocity of 2 deg/s. Thirty-two positions in the 30° radius visual field were tested six times, at luminance levels of 41.62 and 110 cd/m² (background 10 cd/m²). An analysis of RT variance (ANCOVA) was performed.

RESULTS. Median RT increased with age from 370 ms (20–30-year-old subjects) to 440 ms (60–70-year-old subjects). There was a strong dependency of RT from the individual subjects examined (means range, 313–411 ms), from the course of one examination period, from the examination and stimulus luminance, and from the location in the visual field.

CONCLUSIONS. Reaction time during automated kinetic perimetry varies considerably. This study shows that the factors of age, the subject examined, his or her daily condition, the course within one examination period, and the stimulus location and luminance are of relevance. For a much more reliable prediction of individual RTs and thus a precise assessment of local kinetic thresholds, application of some additional kinetic stimuli (RT time vectors) within the intact visual field areas is necessary. (*Invest Ophthalmol Vis Sci.* 2005;46:2633–2638) DOI:10.1167/iavs.04-1413

Since the beginning of the past century, nonperimetric psychophysical studies have shown that simple reaction times (RTs) increase with increasing stimulus eccentricity^{1–3} and decrease with increasing light intensity.^{3–8} More recently, RTs during static perimetric testing have been studied for different reasons. Frisén⁹ described a method in static perimetry that shortens the examination by individually adjusting the inter-stimulus intervals to RT, which leads to an increase in the patient's comfort. Moreover, Bengtsson et al.¹⁰ and Olsson et

al.¹¹ defined RT windows for a new algorithm of threshold estimation in static automated perimetry called SITA (Swedish interactive thresholding algorithm). They rated RTs below a lower limit of 180 ms as false-positive catch trials, thereby saving time for extra presentations of conventional catch trial stimuli. Response times can also be used to remove a large percentage of false-positive responses selectively, further improving the performance of suprathreshold perimetry (Henson and Artes¹²). Furthermore, Rouland and Hache¹³ and Wall et al.¹⁴ attempted to develop special RT evaluation testing methods for the early diagnosis of glaucoma in patients.

RT measurement is even more important in kinetic perimetry than in static perimetry, because RT induces a systematic shift of the scotoma border toward the direction of stimulus movement. As stimuli are typically traveling from nonseeing areas (periphery of the visual field) toward seeing areas (center of the visual field) in kinetic perimetry, RT causes a systematic “shrinkage” of intact visual field area and a systematic increase of visual field defects, respectively. Moreover, variation of RT at subsequent visits may obscure the course of visual field change.

Because traditional kinetic perimeters are operated manually, the results strongly depend on the perimetrist and individual technique. Not only is the angular velocity of the stimulus unknown, but the direction of motion is also undocumented. Thus, the determination of the exact visual field threshold is uncertain, since its measurement varies with the RT of both the perimetrist and the patient examined. Threshold measured with modern computer-controlled perimeters, which automate stimulus presentation and recording of the patient's response, are only affected by the RT of the patient. RT measurements with moving stimuli were first performed by Eischer-Desrivières,¹⁵ who reported shorter response times when moving stimuli were presented in the center of the visual field than when they were presented in the periphery.

In an effort to determine more accurately the location of kinetic thresholds, we studied the influence of subject age, inter- and intraindividual variations, stimulus location in the visual field, stimulus luminance, and vigilance on the RT of healthy subjects during automated kinetic perimetry.

METHODS

Subjects

Thirty-six healthy subjects (ratio of women to men, 20:16) from three age groups (20–30 years, 7:5; 40–50 years, 8:4; 60–70 years, 5:7) participated in the study. The protocol adhered to the tenets of the Declaration of Helsinki. After appropriate informed consent and subject instruction, a health questionnaire was completed including questions about previous vision problems and use of any medications with potential effect on CNS function. Patients were given an allowance to defer travel expenses.

Ophthalmic inclusion criteria for the subjects were as follows: best corrected distance and near visual acuity equal or better than 20/20 OU, spherical ametropia less than or equal to ±6 D, and cylindrical

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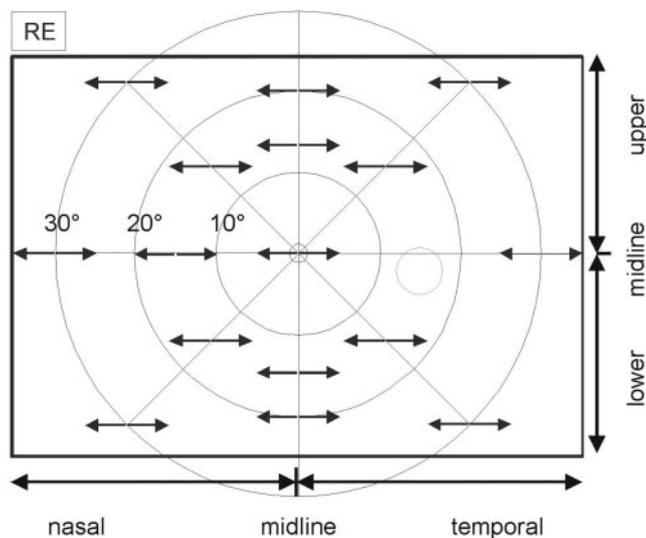


FIGURE 1. Scheme showing vector locations within the examined visual field. The test vectors were located at 16 positions at 0°, 15°, 20°, and 30° eccentricity on the straight and oblique meridians. The pattern was symmetric with respect to the vertical axis, but the blind spot area was not tested. A pair of vectors with opposite directions originated at each location. From the initial point, one target moved horizontally either to the right or to the left. The order of presentation of the vectors was randomized. Each vector was tested six times, with a stimulus luminance of 110 and 41.62 cd/m² each.

ametropia less than or equal to ± 2 D. Furthermore, we required isocoric pupils normal stereopsis (all figures identified, using the Lang II test), normal ocular alignment, normal ocular motility with no history of diplopia, and no relative afferent pupillary defect. The IOP of both eyes had to be less than or equal 20 mm Hg (determined after perimetry by either air pulse or applanation tonometry), normal refractive media as assessed with slit lamp and normal optic disc and macular appearance by direct ophthalmoscopy. Each subject had one eye examined, chosen in random fashion.

Tübingen Computer Campimeter

The Tübingen Computer Campimeter (TCC) presents kinetic stimuli on a calibrated high-resolution video display unit¹⁶⁻²⁰ (1024 × 768 pixels, 75 dpi; Barco, Kippenheim, Germany). At a viewing distance of 30 cm, the 20-in. monitor covers approximately 35° horizontally and 24° vertically of the visual field radius. The background had a homogeneous luminance of 10 cd/m². The fixation mark was diamond-shaped and consisted of four red circles (10 minutes of arc in diameter, identical luminance as the background) that were located at 1° eccentricity. Subjects responded to stimulus perception by pressing a button. Fixation was directly monitored by the examiner through an infrared camera attached to the chin and head support, which also recorded pupil position and horizontal diameter.

Perimetric Settings

The size of the stimuli tested was 26 minutes of arc (corresponding to Goldmann III). Targets moved linearly along vectors with an angular velocity of 2 deg/s within the central 30° visual field (Fig. 1). The test vectors were located at 16 positions at 0°, 15°, 20°, and 30° eccentricity on the straight and oblique meridians. The pattern was symmetric with respect to the vertical axis, but the blind-spot area was not tested. A pair of vectors with opposite directions originated at each location. From the initial point, one target moved horizontally, either to the right or to the left. The order of presentation of the vectors was randomized. Each vector was tested six times with a stimulus luminance of 110 and 41.62 cd/m² each. Invisible stimuli (10 cd/m², same luminance as background) were also presented three times per location. Testing

without visible stimuli served as a false-positive catch trial to see how often a subject pressed the response key without actually having seen a stimulus. The visual field examination could be interrupted anytime according to the subject's or the examiner's needs.

The stimulus appeared suddenly without any acoustic cueing and moved on the monitor until the subject pressed the response button or until the stimulus had moved a distance of 6°. At this point, it disappeared immediately. The time (in milliseconds) between the appearance of a stimulus and the subject's response was defined as RT. To avoid a rhythm effect, we alternated stimulus presentation after pauses of various lengths (1200 or 1800 ms).

Data Management

For analysis, the vector pattern of the left eye was mirrored by the vertical midline to match the right eye pattern. This enabled the comparison of vectors with the same characteristics. Values above 800 ms and below 170 ms were discarded as not arising from immediate response or response to the preceding stimulus, respectively. The limits were similar to those used in experiments by other research groups.²¹⁻²³

Statistical Analysis

A Box-Cox-transformation was estimated in an analysis of covariance (ANCOVA) of the raw readings. As a result, the reciprocal value, distance per 2 seconds, was used as the response in the prediction model, to reach a closer approximation to a normal distribution. In graphs and tables, the values were transformed back for clarification. Data were analyzed with ANCOVAs. For expected values, the 95% confidence interval (CI) was computed.

Experiment Age

In the first experiment, the effect of age on RT was estimated. The RT data of 36 subjects examined once were analyzed by the factors luminance of the signal, age, code, and the covariables eccentricity, number of presentations (nop) and nop². Three age groups (20-30, 40-50, and 60-70 years) were compared. The factor code allowed an estimation of an individual effect for each subject. Eccentricity was the eccentricity (in degrees) of the location where the target appeared in the visual field. Stimulus presentations were assigned consecutive numbers. The covariables number of presentations (nop) and its square nop² were considered to describe a parabolic fatigue trend over the course of one examination, as each curvature was described by a quadratic (parabola) and a linear (ascending-descending) term. The factor effects were given for the 240th of 480 stimulus presentations. Every subject had his or her own fatigue curve. Because of this, a mix of fatigue and learning effect for each individual was possible.

Experiment Code

RTs of the first group (age, 20-30 years) were measured on two different days (interval: 12-153 days). In the ANCOVA model, the factors luminance (of the target presented), eccentricity in the visual field, side of the visual field (nasal, midline, temporal), half (upper part, midline, lower part), code, examination, examination * code (* denotes interaction of two factors), nop, nop², nop * code, and nop² * code were analyzed. Only stimuli that started from the horizontal or vertical midline were classified as midline. Examination had two possible values: first or second visit. In our model, each subject exhibited a systematic deviation from the general difference between visits (i.e., the examination * code interaction). The parabola over nop, too, was estimated for each subject and as a general trend.

RESULTS

Experiment Age

For analysis of the influence of age on RT, 36 normal adults in three groups (20-30, 40-50, and 60-70 years) underwent one

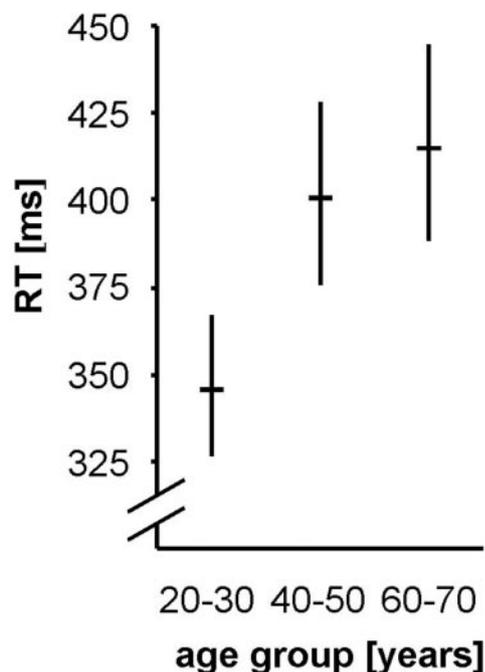


FIGURE 2. Mean RT and related 95% CI by age group (age experiment).

examination on the TCC. The mean RT of the 13,637 valid measurements was 409 ms, with a residual SD of 52 ms. Because of the limitation of the RTs to the preset interval, 61 (0.44%) were too short (i.e., <170 ms), and 129 (0.93%) were too long (i.e., >800 ms) and were therefore excluded from the evaluation.

Age effect had a probability of 0.0004. The least square means (LSM) were 370 ms (95% CI: 351–392 ms) in the 20- to 30-year age group, 425 ms (95% CI: 400–453 ms) at 40 to 50 years, and 440 ms (95% CI: 413–470 ms) at 60 to 70 years (Fig. 2). The factors luminance, age, code, eccentricity; the variables nop and nop^2 ; and the interactions examination * code, nop * code, and nop^2 * code had $P < 0.0001$ in this ANCOVA. At the higher luminance level (110 cd/m^2 vs. 41.62 cd/m^2) the LSM RTs were shorter by 18 ms.

However, the model accounted for just $R^2 = 46\%$ of total variance. The largest part (24%) was explained by interindividual variation in the average RT—the so-called code effect. The eccentricity effect was responsible for 5% of the variance. Approximately 1% of the variance depended on the luminance levels (110 cd/m^2 vs. 41.62 cd/m^2) of the target presented and on age, 0.45% on nop during the experiment, and 0.23% on nop^2 .

The frequency distribution of 427 RTs of all 36 subjects at the center of the visual field at a stimulus luminance of 110 cd/m^2 is provided in Figure 3 (two vectors starting from the center, one in the temporal and the other in the nasal direction) as an example.

Experiment Code

Twelve young normal subjects were examined two times on different days to evaluate the influence of interindividual differences, individual interexamination differences, and the course of the examination (nop). The RT mean of 9157 valid measurements equalled 356 ms and the residual SD was 47 ms. By limiting the obtained RTs to the predefined interval (170–800 ms), we declared 30 (0.33%) to be too short and 30 (0.33%) to be too long in this experiment. The model ex-

plained 30% of total variance. The ANCOVA results are shown in Table 1.

At the lower stimulus luminance level (41.62 cd/m^2) mean RT equalled 318 ms (95% CI: 314–323) versus 307 ms (95% CI: 301–314) at the higher luminance level (110 cd/m^2). RT increased with eccentricity on average by 2 ms per degree. At the center, LSM equalled 326 ms (95% CI: 322–330 ms), and at 30° eccentricity 386 ms (95% CI: 376–397 ms). RT was 8 ms longer in the nasal hemifield than in the temporal (nasal mean, 360 ms, 95% CI: 358–362 ms; temporal mean, 352 ms; 95% CI: 350–355 ms). RT for stimuli that originated from the vertical midline was 363 ms (95% CI: 361–366 ms). In the lower hemifield, a mean RT of 353 ms (95% CI: 350–355 ms) was observed; in the upper hemifield, 367 ms (95% CI: 365–369 ms); and at the horizontal midline, 356 ms (95% CI: 354–359 ms). The mean of the individual RTs (code) ranged between 313 and 411 ms. In the second examination, RT was on average 10 ms higher than in the first visit (SE, 1 ms). Repeatability variance was 0.57% of total variance.

The average RTs in all 12 subjects in both examinations and the related 95% CIs are shown in Figure 4. Highlighted by this summary are the interindividual differences in RT, but also intraindividual ones, that were between –19 and +46 ms.

On average, over all subjects, the predicted RTs increased from 326 ms for the first stimulus to 344 ms for the last one. Average curvature of the fatigue trend indicated that an initial increase in RT was reversed to a decline at the end of the examination period. Each subject examined had a separate course modeled by a linear (nop) plus a quadratic (nop^2) term. The regression lines for each subject are presented in Figure 5.

DISCUSSION

Our experiments on normal subjects on the Tübingen Computer Campimeter represent the first carefully performed trials undertaken in kinetic perimetry to determine the effects of age, the subject examined, his or her daily condition, and the course within one examination period, as well as stimulus location and luminance on RT. We found them all to have significant effects on RT. Our findings are consistent with previous similar reports of static perimetry RTs but highlight some of the key differences in these methodologies and how various factors alter RT.

According to Finlay,²⁴ an object is perceived as moving immediately when it moves with an angular velocity of 1 to

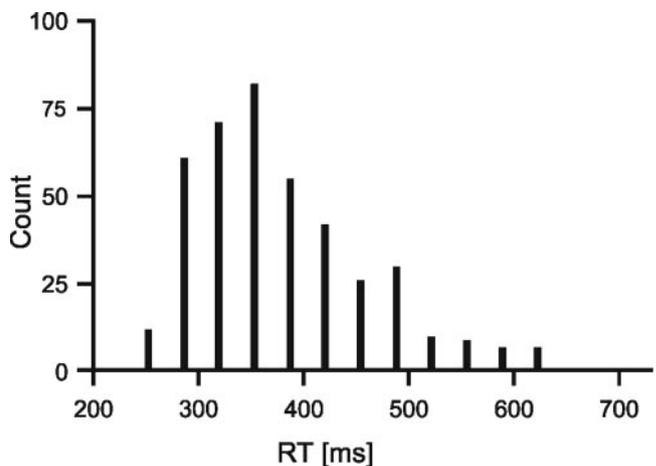


FIGURE 3. Frequency distribution of 427 RTs of all 36 subjects at the center of the visual field at a stimulus luminance of 110 cd/m^2 (two vectors, each tested six times).

TABLE 1. ANCOVA Table: Experiment Code

Source	DF	Sum of Squares	Variance (%)	Mean Square	F Ratio	P
Luminance	1	29.37	1.26	29.37	164.36	<0.0001
Eccentricity	1	126.73	5.45	126.73	709.24	<0.0001
Side	2	9.82	0.42	4.91	27.48	<0.0001
Half	2	22.27	0.96	11.14	62.32	<0.0001
Code	11	200.57	8.62	18.23	102.05	<0.0001
Examination	1	13.34	0.57	13.34	74.63	<0.0001
Examination*Code	11	61.22	2.63	5.57	31.15	<0.0001
nop	1	19.55	0.84	19.55	109.41	<0.0001
nop*Code	11	15.79	0.68	1.44	8.04	<0.0001
nop*nop	1	2.31	0.10	2.31	12.91	0.0003
nop*nop*Code	11	7.91	0.34	0.72	4.03	<0.0001
Model	53	700.47	30.10	13.22	73.97	
Error	9, 103	1, 626.54	69.90	0.18		
Total	9, 156	2, 327.02				

DF, degrees of freedom.

2 deg/s. Thus, the target velocity in our study (2 deg/s) was more conservative than that proposed by Johnson et al.²⁵, being 4 deg/s.

Age

In general, our RT data with moving stimuli are in accordance with several but not all studies regarding similar testing of healthy subjects. A significant effect of age on RT was demonstrated in this study. The mean RT was 55 ms higher in the group aged 40 to 50 years than in the group aged 20 to 30 years (370 ms) and 70 ms higher in the group aged 60 to 70 years than in the group aged 20 to 30 years, with no overlap in the related confidence intervals. The increase in RT between the group aged 40 to 50 years and the group aged 60 to 70 years was smaller than between the groups aged 20 to 30 years and 40 to 50 years. Comparable data regarding the influence of age on RT in kinetic perimetry have not been reported. Porciatti et al.²¹ used two different age groups (mean ages of 29 and 70 years) to differentiate between the influences of motoric (responding to a stimulus) and sensory (seeing the stimulus) components of delayed RT with age. These investigators mea-

sured RTs for motion onset, as the study required normal subjects to respond as quickly as possible by button-press (simple RT) to a visual stimulus. At the lower speed level (1 deg/s) it was found that the older group had an average increase of RT of 75 ms compared with the younger group. According to our data, the difference between the two groups with comparable ages was similar (70 ms) in kinetic perimetry. An increase in RT of 9 ms per decade in measurements of static suprathreshold perimetry in patients has also been described—however, with a weak correlation (Pearson $r = 0.18$; Artes et al.²³). This study had a group mean RT (451 ms) that was slightly longer than ours (409 ms). Only one study (Rouland and Hache¹⁵) found no significant difference in the RT measurements between two age groups studied during static perimetry with normal subjects (mean RTs approximately 470 ms). However, in their research, the age groups were closer in age (26–40 and 41–69 years).

Stimulus Luminance and Location

The influence of stimulus luminance on RT in perimetry has been described in the literature. Cattell²⁶ found that there is a shorter RT with a brighter stimulus luminance, whereas Piéron⁷ went further to develop his own law, which describes a dependency of RT on luminance. A detailed history of the developments in the influence of luminance on RT can be found in Mansfield,⁶ where RT is described by two components: a fixed one and one that follows a power function of

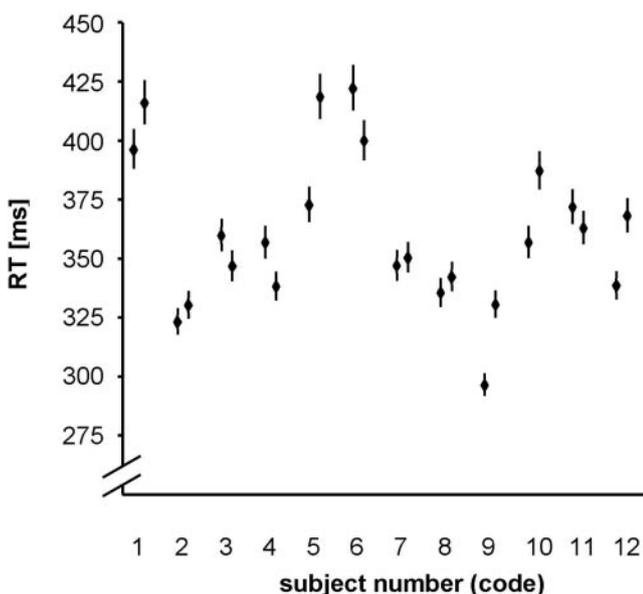


FIGURE 4. Mean RT and related 95% CI by examination in 12 subjects who underwent two examinations on different days (code experiment).

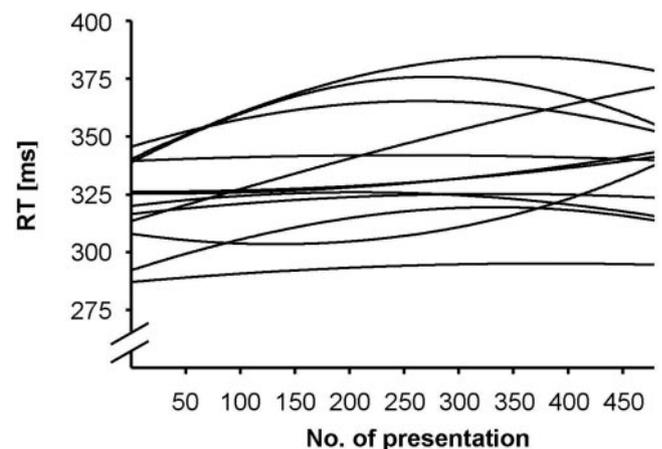


FIGURE 5. Individual regression lines over the course of one examination in 12 subjects (code experiment).

light intensity. Because we studied only two different intensities, we cannot analyze our data by a power function. However, consistent with previous reports, we found a decrease in RT with increasing intensity.

In this experiment, the increase of RT per degree eccentricity was 2 ms on average. Wall et al.²² found an increase of RT of approximately 1 ms/deg when using suprathreshold stimuli in static perimetry with increasing visual field eccentricity, from the center to 50° (374 ms at the center). Other investigators have reported an increase of approximately 20 ms between the RT value at the center and at an eccentricity of 30° (average increase of 0.7 ms/deg) for static stimuli presented with a stimulus-luminance of 14 cd/m² on a cathode ray tube (Ando et al.²⁷). Osaka²⁸ reported an increase of 40 ms from the center to an eccentricity of 30° (average increase, 1.3 ms/deg) with a signal luminance of 8.5 cd/m² with static stimuli. In addition to that, Osaka described a nasotemporal difference in RT. In the temporal area of the visual field RTs were shorter than in the nasal, as seen in the two tested subjects. These differences increased from 4.5 ms (at 10° eccentricity) to 11 ms (at 50° eccentricity). In agreement with these results, we found RT to be, on average, 8 ms longer in the nasal area than in the temporal part of the visual field. Osaka theorized that these differences in RT depend on interhemispheric transmission time. The extent of the influence of eccentricity seems to depend on several different experimental conditions. It ranges from 1 to 2 ms per degree of eccentricity. Our data suggest a greater effect of eccentricity on RT in kinetic situations than in static ones.

Individual Variation

In a previous report²⁹ we demonstrated that RTs showed considerable inter- and intraindividual variation with individual LSMs ranging from 305 to 454 ms. In the current study, we expand on these observations and present RT data from 12 subjects whose LSMs varied over a range of 98 ms (313–411 ms). Remember that we tested only healthy subjects between 20 and 30 years of age. Interindividual RT differences have been reported by other authors: Artes et al.²³ reported considerable RT differences between subjects examined with suprathreshold static perimetry and reported individual means that differed between 316 and 908 ms. However, these subjects (aged between 12 and 81 years) were patients attending an optometric practice for routine eye care, potentially having risk factors for glaucoma or neurologic disease. Thus, patients may be expected to have a much broader range of interindividual differences in RT. Frisén⁹ reported about the interindividual differences of mean RT (320–660 ms) in 100 subjects during automated static perimetry on a ring screener, while Henson and Artes¹² reported large intersubject differences in the average latency and its dispersion in measurements of suprathreshold perimetry. Another report about intersubject variability in RT was published by Breitmayer and Breier³⁰ (mean RT ranged over 120 ms), describing experiments concerning the influence of background color on RT to increment-decrement spot stimuli of varying diameters. The subjects tested were four normal subjects, whose ages ranged from 20 to 46 years.

The examination effect caused some variance, showing that in each examination period most subjects had different mean RTs. The average RT-increase between the first and second session was small (10 ms). The interaction examination * code was also significant. Some individuals were faster in the first examination and others in the second one, by various degrees. Kobrick and Sleeper³¹ examined RT for light signal detection in 24 male soldiers aged 18 to 35 years on different days. They repeated the task three times, without finding any significant

effect between measurements on different days under the same conditions. On the contrary, Ando et al.²⁷ reported significant training success over a period of several days. However, the stimuli in this study were presented at only three different locations in the visual field to subjects having practiced 45 times. As the mean RT of our second examination was greater than in the first, there seems to be no learning effect regarding RT. This lack of a learning effect may depend on the low number of task repetitions.

Intraexamination Course

In our measurements we found a trend over the course of one examination (nop). This effect is similar to short-term fluctuation, the scatter of the differential luminance threshold observed during a single visual field test in static perimetry. For nop, 1 was the first stimulus presented, 2 was the second, up until 480 for the last stimulus. To obtain an optimal fit of the model, we used a linear and a quadratic term in the prediction model. The coefficient of the common linear effect suggested that there is a general fatigue effect. The predicted RT increased from 326 ms for the first stimulus to 344 ms for the last one. Common curvature was such that the average fatigue curve would increase at first. However, it would then decline at the end of the examination period.

To analyze these courses further, each individual was to have his or her own course with a linear and quadratic part (nop * code, nop² * code). Because of this, a particular mix of fatigue and learning effect was possible for each individual. It is notable that in 11 of 12 participants, a fatigue effect was detected. In one, a slight shortening of RT appeared, which could be interpreted as a learning effect. In this single participant, a fatigue effect also appeared in the first half of the examination that was compensated for in the second part. Marra and Flammer³² detected neither a learning nor a fatigue effect during a perimetric session using threshold determinations in static perimetry common to healthy persons and patients with glaucoma or cataract. To date, there have been no comparable studies published concerning the interpretation of RT measurements over the course of one examination.

Nevertheless, it should be mentioned again that we tested only healthy subjects and that these results are applicable only to this group. For common diseases such as glaucoma or other optic neuropathies, as well as neuroophthalmic diseases, further investigation is necessary. It is also especially important to know whether individual RT varies when approaching the scotoma border.

CONCLUSION

We demonstrated that RT during automated kinetic perimetry varies considerably, even in normal subjects. Our experiments show that well-known factors such as location in the visual field and stimulus luminance are relevant, but that age, and individual inter- and intrasubject variability are also important factors.

Precise RT predictions can be made when presenting only a few (approximately 10) so-called RT vectors, which can be easily integrated in modern computer-controlled perimetric test procedures. By use of this method, one can assess and reduce the systematic shift of scotoma borders measured with moving stimuli and more accurately determine the actual threshold.

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