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Age-corrected normal differential luminance values for the entire 80° visual field applying three threshold estimating strategies, using the Octopus 900 perimeter

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1. Introduction

The knowledge of instrument-specific age-corrected normal values of DLS is essential for the evaluation of VF findings. It is well known that DLS decreases with normal ageing thus influencing the hill of vision (HOV). [13,22,32,33] It is therefore important to examine a sufficient amount of normal subjects over the entire relevant age range to achieve a reliable data base of normal values for each test location. Additionally it is of great benefit to be able to define normal local threshold values for locations which are not included in the test grid. Schwabe et al. [68] first introduced a smooth mathematical model describing the normal HOV in a 30° VF. As many diseases of the retina and the visual pathway influence not only the central VF but also the periphery, it is of great advantage to know the normal DLS values not only of the 30° VF but also of the 80° VF. This study extends the set of normal values and the corresponding smooth mathematical model to the entire 80° VF of the Octopus 900 (O900) perimeter (Haag-Streit Inc, Koeniz, Switzerland).

The O900 instrument, the successor of Octopus 101 (O101) perimeter, produced by the same manufacturer, is a new automated static and kinetic perimetric instrument with several reforms compared with its precursor. The most obvious differences are the smaller cupola radius (30 cm in O900 and 42.5 cm in O101) and the used light source: the O900 uses white LED light sources for background illumination and for stimuli presentation whereas the O101 uses halogen light sources.

The major goal in modern perimetry is to achieve maximal diagnostic benefit with minimal examination duration. It has been shown that with shorter algorithms it is possible to achieve smaller inter-subject variability and thereby even smaller depressions in the VF will show a statistical and clinical significant deterioration. [8] To decrease the test duration of threshold estimating strategies in Octopus perimeters, the German Adaptive Threshold Estimation (GATE-i) algorithm was developed, [67] which is independent of the perimetric grid.

In common practice, 10 cd/m^2 (the Goldmann standard) is the most frequently used background luminance level. According to earlier studies, the shape of the HOV depends on the background luminance. [2]

The aim of the present study was to evaluate and compare age-related normative hills of vision for the entire 80° VF with three automated static strategies (conventional 4-2-1, dynamic and GATE-i) and with two background luminance levels (10 cd/m^2 in conventional strategy and GATE-i and 1.27 cd/m^2 in dynamic strategy) obtained with the O900 perimeter by applying a smooth mathematical model. Asymmetries and the effect of age on the HOV were investigated. Furthermore, we analyzed and compared the retest-reliability, i.e. the SF and LF, and the number of presented stimuli of the three strategies. In a third step we seeked to find out how concordant the examination results of the two perimeters, the O101 and its successor, the O900, with the new GATE-i strategy are.

2. Subjects and methods

Participants

Volunteers were recruited by placing an advertisement in a local newspaper and by displaying handbills on bill-boards and in different public places. 122 interested people between 10 and 79 years of age were screened via phone call, and 88 of these were invited for a thorough examination by an ophthalmologist (JN). Informed consent was obtained from each participant after the procedure had been accurately explained. For subjects younger than 18 years consent was given by a guardian as well. The study was approved by the local Independent Review Board and the protocol observed the tenets of the Declaration of Helsinki.

Inclusion criteria were as follows:

1) spherical ametropia max. ± 6 dpt, cylindrical ametropia max. ± 2 dpt
2) corrected distant visual acuity ≥ 1.0 (20/20) for subjects up to 60 years of age, ≥ 0.8 (16/20) for subjects from 61 to 70 years of age, ≥ 0.6 (12/20) for subjects older than 70 years of age

3) isocoria, pupil diameter > 3 mm
4) intraocular pressure ≤ 21 mmHg
5) anterior segments normal, no relevant opacitities of the central refractive media
6) normal appearance of the optic disc (cup to disc ratio = CDR ≤ 0.5, intraocular difference of CDR < 0.3) and normal central and peripheral fundus findings according to direct and indirect opththalmoscopic examination with undilated pupils

Exclusion criteria were defined as:

1) amblyopia, strabismus, ocular motility disorders
2) retinal pathologies
3) glaucoma, suspicion of glaucoma, ocular hypertension, macular degeneration
4) pathological color vision test results (Ishihara and Standard Pseudoisochromatic Plates color vision test)
5) eye surgery (except cataract surgery), LASIK
6) history or signs of neuro-ophthalmological diseases
7) mental or neurological diseases
8) acute infections
9) diabetes mellitus, diabetic retinopathy
10) history of coronary heart disease, stroke, migraine, vasospasm/ Morbus Raynaud
11) miotic drugs
12) drugs indicating severe general diseases (e.g. anti-diabetic or antihypertensive medication for subjects up to 70 years of age; one anti-hypertensive medicament was allowed for subjects greater than 70 years of age)
13) drugs influencing reaction time
14) pregnancy, nursing
15) heavy smoking (> 10 cigarettes per day), alcohol abuse
16) suspected lack of compliance

Examination procedure

For the VF examination, the dominant or the non-dominant eye (Rosenbach`s fixation test) [63] and the sequence of the three used strategies were randomized, using lists prepared in advance to ensure a balanced design and kept under lock by a third person (EK) that disclosed the individual assignment only immediately prior to the first perimetric examination. Thin-rimmed glasses with adequate near correction adjustment for age inside the central 30° were provided for each subject. Test-subjects had at least one break in the middle of each examination and one between the examinations, each break lasting at least five minutes. The whole procedure including three perimetric surveys and the breaks took 60 - 90 minutes.

Every fifth and sixth subject of each age-group was asked to attend to the perimetric examination two more times for assessing retest reliability. If the test subject was not able or not willing to participate in the retest part, the seventh subject, then the eighth one was asked as necessary. We used the same eye and the same order of strategies as in the first investigation.

25 subjects (14 men, 11 women between 16 and 76 years of age) were examined on a further appointment with the GATE-i strategy (see below) on both, the O900 and the O101, to compare the DLS values achieved with the two perimeters. The same eye was used for the examination as on the first appointment and a randomisation list for the order of the two investigations was used. Again, the subjects had breaks of at least 5 minutes between the two examinations as well as in the middle of each examination.

Technical data

The main differences of the two perimeters used in this study, the O900 and the O101, are shown in Table 1.

We assessed the background luminances of the two perimeters with a preset background luminance of 10 cd/m^2 with the Minolta LS-100 luminance meter (Konica Minolta Holdings Inc., Tokio, Japan) in 25 locations within 70° eccentricity. In the O900, the background luminance decreases from 15.18 cd/m^2 and 14.27 cd/m^2 in the upper two corners of the cupula (50°/50° and -50°/50°, respectively) to 9.68 cd/m^2, 9.85 cd/m^2 and 8.9 cd/m^2 in the lowest part of the cupula (50°/-50°, 0°/-50° and 50°/-50°, respectively), values are means of two measurements. In the O101 we assessed a background luminance of 8.21 - 10.41 cd/m^2 with the highest values of 10.41 cd/m^2 and 10.36 cd/m^2 in 0°/-30° and 0°/-15° and the lowest values in the four corners: 8.21 cd/m^2 in 50°/-50°, 8.65 cd/m^2 in both 50°/50° and -50°/50°, and 9.03 cd/m^2 in -50°/-50°.

The test grid included 86 stimuli which were condensed towards the centre. The test point arrangement is shown in Fig.1 and Fig.2. White stimuli with the standard size of Goldmann III (26´) were used.

The conventional, the dynamic and the GATE-i strategies have several different features. The conventional strategy uses a 4-2-1 dB-bracketing procedure with two reversals. In the dynamic strategy the luminance step sizes increase with an increasing depth of a defect and vary between 2 and 10 dB; the threshold is crossed only once. [71,73-75]

GATE-i ("i" stands for initial) uses an algorithm which is based on an altered "4-2 dB" staircase strategy. After testing pre-defined seed locations and comparing them to the age-corrected normal HOV, the seed location with the smallest absolute deviation from the normal HOV is used to translate the values of the entire HOV. For the remaining locations, testing starts slightly above the expected normal threshold. Resulting in a positive answer a 4-2 dB bracketing strategy starts which is complete after two reversals. Resulting in a negative answer a stimulus of maximum brightness is presented. The interrogation is terminated if this stimulus cannot be seen. In the case of a positive answer to the maximal stimulus intensity a 4-2 dB bracketing procedure starts from the initial stimulus at that location. The value between the dimmest stimulus seen and the brightest stimulus not seen is appointed as local threshold. [67]

The GATE algorithm, which is applied in subsequent sessions, reverts to previously determined local thresholds instead of referring to age-related normal values as in GATE-i. Further characteristics of each strategy are shown in Table 2.

The maximum stimulus luminance – which is also the reference luminance used in the dB-scale – is approximately 1 280 cd/m^2 (4 000 asb) for the conventional and the GATE-i strategies (background luminance 10 cd/m^2) and 320 cd/m^2 (1 000 asb) for the dynamic strategy (background luminance 1.27 cd/m^2). Accordingly, in the conventional and the GATE-i strategies a stimulus luminance of 1 280 cd/m^2 equals 0 dB whereas in the dynamic strategy a stimulus luminance of 320 cd/m^2 equals 0 dB.

Sixteen stimulus locations (see Fig.7) were measured twice during one examination in both the conventional and the dynamic strategies (not in the GATE-i strategy) to measure the SF.

False-positive (FP, positive response without any stimulus presented) and false-negative (FN, no response to brightest possible stimulus in a given location with documented response to a previously presented dimmer stimulus) catch trials were presented for qualitiy control. For the conventional and the dynamic strategies the preset rate of 5% of FP and 5% of FN catch trials was used. During the GATE-i strategy the FP and FN catch trials were set to 2%.

The subjects´ fixation was controlled steadily with an integrated infrared video camera and the perimeter paused automatically if the subject lost fixation or closed the eye. Additionally, the examiner steadily controlled the fixation via monitor during the examination.

For the comparison of the two instruments, the same test grid was used as in the previous investigations with the exception of one test point located at 0°/-8°, as in the O101 the integrated infrared camera was positioned at just this location. 4% of the stimuli were presented as FP and four percent as FN catch trials in this part of the investigation.

Analyses

The coordinates of the left eyes were mirrored at the vertical meridian. Local DLS values below 1 dB were excluded from the analyses. Points inside the blind spot were excluded also.

Model

We included the known factors (i.e. stimulus location and age of the testee) which affect local DLS values of healthy people in the variables for modelling the HOV. [13,22,31,33,68] We exploited the earlier knowledge of the profile of the HOV and the influence on it of ageing [44,52,68]: a pointed summit in the centre, followed by a gentle slope or even a plateau, which is larger towards temporal and inferior hemispheres, and subsequently increasing steepness towards the periphery. Ageing reduces local DLS values to a higher extent in the mid-periphery and periphery than in the central VF, resulting in an overall steeper profile of the HOV in older subjects. [68] The model for the HOV in the O900 was defined using the responses in all 86 test locations obtained with conventional strategy, and then fitted to the dynamic and the GATE-i strategies, using the responses obtained with these strategies, to estimate DLS values at any VF location. The modelling procedure has been described by Schwabe et al.. [68] We modified the model to better fit the normative data set, using the JMP software (version 5.1, SAS Institute Inc., Cary NC 2003, USA) including only those interaction terms increasing the adjusted R^2 (coefficient of determination). R^2 was used to evaluate the fit of the model with respect to the measured values.

Ten test-locations in the very upper and nasal part of the VF (see Fig.2 and Fig.7) were defined as “rim”. Their variance was modeled to be larger – as expected – while their mean DLS values were fitted with the smooth model.

Retest reliability

Long- and short-term fluctuation were measured as square root of half the variance of differences of DLS thresholds measured during different examinations and at different times within one examination, respectively. That is an alternative computation to the original analysis of variance approach with factors subject, location and their interaction. [4,24] Short-term fluctuation was measured within the first examination of all patients, while LF was assessed for the 14 patients examined three times.

3. Results

Participants/ investigations

2 of the 88 invited subjects had to be excluded from the study before perimetry, one due to a facial nerve paresis and one because of spherical ametropia that was too high. Two further subjects had to be exluded immediatelly after perimetry: one because of a suspected lack of compliance and one because of a homonymous VF defect. He underwent further diagnostics in the eye hospital. During the analyses, three further subjects were excluded: two due to poor attendance (>50% of the examinations were missing) and one because of repeatedly poor perimetric quality control (>30% FP). 81 participants were remaining, 10 to 13 participants per decade of age. The age and gender distribution of the subjects (35 male and 46 female) are shown in Table 3. 40 subjects were investigated using their dominant eye, 41 using their non-dominant eye.

Five investigations with a FP- or FN-rate greater than 30% had to be excluded and the investigations of these subjects were repeated during a separate appointment. Two subjects had a few test locations unevaluated in one of the three investigations because of measurement problems (one in the conventional strategy, one in the dynamic strategy), and the related test locations were excluded.

7 of the 14 subjects who were investigated three times on three different appointments for retest-reliability conducted the investigations with their dominant eye, seven with their non-dominant eye. The first retest was completed within one month from the first investigation (min. 5 days, max. 27 days, mean 16.5 days), 13 subjects completed the second retest after at least two months from the first retest (min. 76 days, max. 147 days, mean 108.6 days). One subject was examined after only eight days.

For the comparison of the two perimeters 9 of the 25 subjects who attended this part of the study conducted the investigation with their dominant eye, 16 with their non-dominant eye. Twelve subjects were examined with the O900 first, 13 with the O101 first. The VFs of one subject had to be excluded because of more than 50% unevaluable test-locations. Altogether 24 VFs for each perimeter could be analyzed.

Local thresholds

Fig.1 and Fig.2 show the test-grid and the mean local thresholds [dB] for the subjects between 40 and 49 years of age for all three strategies for each test location.

Within the entire 80° VF except in locations earlier defined as “rim”, the dynamic strategy showed 0.21±2.50 dB (mean±SD) higher local DLS values than the conventional strategy and the GATE-i strategy 0.98±2.73 dB (mean±SD) higher local DLS values than the conventional strategy. The difference between the dynamic and the GATE-i strategies was 0.77±2.72 dB (mean±SD). Table 4 shows the results for each age group.

Within the 30° VF the dynamic strategy showed 0.26±2.45 dB (mean±SD) higher local DLS values than the conventional strategy and the GATE-i strategy 1.08±2.57 dB (mean±SD) higher local DLS values than the conventional strategy. The mean difference between the dynamic and the GATE-i strategies was 0.81±2.59 dB (mean±SD).

Model

Age and test location in polar coordinates (eccentrity [*ecc*] and angle [*a*] of the meridian) and their interactions were used as variables in constructing the model. The angle was transformed by sine and cosine to achieve continuous data, and the apex of the HOV was set to the VF centre. The shape of isopters is determined by the interaction of *ecc* and transformed *a*, where sine *a* moves the isopter vertically and cosine *a* shifts the isopter horizontally. The elliptic and a little temporal downward tilting form of the isopters was taken into account by transforming $2 \cdot a$. Using the variables *age* and age^2 allows for the effect of ageing in the altitude (i.e. DLS values) and interactions with *ecc* and functions of *a* for the shape change of the HOV. Using higher order polynomials in *ecc* is needed to model the steepness in the periphery and the central peak of the HOV. The formulae used in determining the HOV are shown in the Appendix. Fig.3 shows diagonal sections through the model for the HOV for 45-year-olds with all three strategies and the means of the measured DLS values in the cohort of 40-49 year-olds. Fig.4 shows the smooth mathematical model for the GATE-i strategy for 15-year-olds, 45-year-olds and 75-year-olds.

The conventional strategy had a coefficient of determination R^2 of 0.75, indicating that the variance of predicted values, calculated with the model, is 75% of the variance of the measured values.

Asymmetry

In the temporal part of the VF, with all three strategies, DLS values first decrease to a greater extent than in the nasal part of the VF (see Fig.5). Therefore DLS values at 10° eccentricity are for all three strategies and all age-groups at the horizontal median slightly higher in the nasal part of the VF. For 45-year-olds, the difference is 0.50 dB for the conventional strategy, 0.59 dB for the dynamic strategy and 0.33 dB for the GATE-i strategy. The situation is reversed at about 20° eccentricity. For external locations, the mean DLS values are higher in the temporal hemifield. The difference between nasal and temporal DLS values is even more pronounced in the periphery (see Fig.5 and Fig.6). The differences for 45-year-olds (conventional strategy / dynamic strategy / GATE-i strategy) are at 25° 0.60 / 0.47 / 0.66 dB and at 60° 8.37 / 7.39 / 11.37 dB. This is due to a greater decrease in the nasal part of the VF as compared to the temporal part of the VF beyond 20° eccentricity.

In the vertical profile cut (90°-270°), for all ages and all eccentricities, local DLS values in the inferior part of the hemifield are higher than local DLS values in the superior part (see Fig.6).The differences are more distinct for higher eccentricities due to a greater decrease of the superior hemifield. The differences for 45-year-olds (conv. / dyn. / GATE-i strategy) are at 10°: 0.89 / 1.10 / 0.77 dB, at 25°: 2.67 / 3.06 / 2.58 dB and at 60°: 9.00 / 9.06 / 9.87 dB.

The greatest decrease in the VF with eccentricity occurs in the superior hemifield. The decrease from the centre to 60° eccentricity was 20.94 / 19.53 / 21.82 dB (conv. / dyn. / GATE-i strategy) for 15-year-olds, 24.10 / 23.00 / 24.47 dB for 45-year-olds and 27.26 / 26.48 / 27.13 dB for 75-year-olds.

Ageing

Fig.5 and Fig.6 show, that the DLS decreases with age – at least along the vertical and horizontal meridian – in a non-linear way. Until the age of about 50 years, the DLS decreases only gradually, and after 50 years this decrease is accelerated. Fig.6 demonstrates, that the central sensitivity increases slightly until the age of about 30 years and decreases afterwards. Ageing is more pronounced in the periphery (see Fig.5 and Fig.6). Therefore, the HOV becomes steeper with age (see Fig.4 and Fig.5). The greatest decrease in DLS values with age occurs in the nasal and superior periphery. At 60° on the horizontal meridian in the nasal part of the VF the difference of DLS values of 15- and 75-year-olds is 7.91 dB with the conventional strategy, 8.13 dB with the dynamic strategy and 6.25 dB with the GATE-i strategy. At 60° on the vertical meridian in the superior part of the VF, the differences are 7.98 dB for the conventional strategy, 8.50 dB for the dynamic strategy and 6.53 dB for the Gate-i strategy. At 25° eccentricity, the decrease of the VF with age is only slightly more pronounced in the superior and nasal than in the inferior and temporal hemifield for all three strategies.

Residual standard deviation

We calculated the residual SD seperately for the 30°-, the 30°-80°- and the 80°-VF as well as for locations defined as rim. Results for all three strategies are shown in Table 5. For the definition of locations defined as “rim” see “Subjects and Methods/ Model”, Fig.2 and Fig.7.

Retest reliability

16 stimulus locations (see Fig.7) were measured twice during one examination in both the conventional and dynamic strategies to measure the SF. One subject showed a typical lens rim artifact with the conventional strategy covering two of the above mentioned stimulus locations, and those two measured results were therefore excluded from the SF calculation.

SF was 1.4 dB for the conventional and 1.5 dB for the dynamic strategy. For the GATE-i strategy no repeated measurements were conducted in this study and the short-term fluctuation can therefore not be determined.

To measure the LF, 14 randomly selected subjects (2 per decade) were examined three times with all three strategies. The mean differences and LF of local DLS values are shown in Table 6.

Number of presented stimuli

In order to compare the duration of an investigation equitably with each of the three strategies, the mean number of stimuli presented in an investigation excluding strategy specific stimuli, (i.e. the number of stimuli presented for catch trials as well as double measurements of thresholds for the short-term fluctuation) was calculated. Thus, differences in the time a subject took as a break, in stimulus-duration, interstimulus-interval, etc. were not taken into account. Table 7 shows the results inclusive of one outlier observed with the conventional strategy. Without that outlier (Fig.8 extreme right), the mean total number was three less, but the SD of the total number was ten stimuli less with the conventional strategy. Within the 80° VF the number of stimuli presented, compared to the conventional strategy, was reduced by 27.7% with the dynamic strategy and by 17.6% with the GATE-i strategy. In the 30° VF the number of stimuli was reduced with the dynamic strategy by 42.9% and with the GATE-i strategy by 19.4%.

Comparison of the O900 with with the O101

For comparison of the two perimeters, the O900 and the O101, we used the GATE-i strategy (see “Technical Data”) with a background luminance of 10 cd/m^2. For the vast majority of the locations the mean difference varied between -1.5 dB and 1.5 dB; on average the local DLS values obtained with the O101 were 0.27 dB higher than those obtained with the O900, SD of differences was 3.2 dB. Only in two locations in the extreme temporal periphery (68°/-38° and 80°/0°) the O900 showed local DLS values more than 5 dB higher than those obtained with the O101. At six locations in the upper most and nasal part of the VF local DLS values were by 1.5 – 2.5 dB higher in the O101 than in the O900. Mean differences for each localisation can be found in Fig.9.

Quality control

All 327 VFs fulfilled the pre-defined quality criteria. Using the conventional strategy FP rates were 0.0 to 28.6% (mean 4.9%) and FN rates were 0.0 to 8.3% (mean 0.4%). Using the dynamic strategy FP rates were 0.0 to 27.8% (mean 3.9%) and FN rates were 0.0 to 14.3% (mean 0.5%). With the GATE-i strategy FP rates were 0.0 to 30.0% (mean 5.3%) and FN rates were 0.0 to 16.7% (mean 0.9%).

4. Discussion

Sample size

The sample size was chosen to be sufficient to estimate tolerance intervals with coverage 95% and confidence 95% that are longer than the shortest thinkable one, the one achieved with infinite sample size, by 15%. An equal amount of dominant and non-dominant eye samples were included in each of the seven age decades and the same number of subjects were in each of the age decade groups, thus the sample size was rounded to the nearest multiple of 14. The sample size was smaller than that in the normative study of Bengtsson and Heijl. [9] However, this study design differed from their study in some factors: (i) The whole study was conducted in one centre and with the same personnel and equipments. (ii) An ethnically homogenous population was investigated, and (iii) uniform age distribution was possible. Thus, sub-groups were not necessary in data analysis.

Other strategies (SITA Standard, FASTPAC, TOP)

As we are going to compare our results with the results of studies investigating other strategies like SITA Standard (SITA: **S**wedish **I**nteractive **T**hresholding **A**lgrorithm), FASTPAC and TOP (**T**endency **O**riented **P**erimetry), we first want to outline the main characteristics of the named strategies.

SITA Standard: The SITA algorithms are mathematically complex procedures. The algorithm provides a local a-priori-distribution for normal subjects as well as for glaucoma patients for each location in a rectangular 6°-test grid. During testing, a substantial VF model estimates thresholds and also assesses the certainty to which the threshold is known at each point. When a predefined threshold certainty is reached, testing ceases. [11] Furthermore reductions in test time are achieved by adapting the interstimulus interval to the patient`s response speed and by alternative estimation of FP response rates which does not require catch trials. [1,55] The strategy can only be used with the Humphrey perimeter and a rectangular 6°-test grid and, as the a-priori-distribution only accounts for glaucoma, it is only released for glaucoma patients. [66]

FASTPAC: The step size is 3 dB and the bracketing procedure stops after a single crossing. For half of the stimulus locations the first stimulus is presented 1 dB brighter than the expected threshold whereas for the other half the first stimulus is presented 2 dB dimmer than the expected threshold. [26,58]

TOP: Tendency Oriented Perimetry has been developed for the Octopus 101 and 300 series perimeters. [41,56] Each test-location is assessed only once and the subject`s response is used not only to determine the local DLS value at this position but also to adapt the local DLS value at the neighbouring points. [47,55] As the method is completely systematic and not oriented towards certain pathological patterns, TOP is not limited to a specific disease.

All three strategies, SITA Standard, FASTPAC and TOP do not refer to a smooth mathematical model.

Local thresholds and residual SD

Within the entire 80° VF the dynamic strategy showed 0.21 dB (mean) higher local DLS values than the conventional strategy, the GATE-i strategy 0.98 dB (mean) higher local DLS values than the conventional strategy, and the dynamic strategy 0.77 dB (mean) lower DLS values than the GATE-i strategy. All differences are less than the measuring accuracy of 1 dB and therefore negligible.

For all three strategies, variability increased towards the periphery. Our results therefore agree with previous studies. [35,45,51,60,64,77] The differences of the residual SDs between the strategies were all less than 0.5 dB. With a measurement accuracy of 1 dB those were considered negligible.

The different factors which can have an effect on variability were nonetheless assessed. As the subjects were examined with all three strategies on the same day in a randomised order, factors like training- or fatigue-effects resulting from investigations done earlier on the same day affected all three strategies. [36] Fatigue-effects within a perimetric session have been regarded as contradictory. [34,38,53,69] However, even if a longer duration would lead to lower DLS- and higher residual SD-values, this cannot explain the higher local thresholds of the GATE-i strategy compared to the dynamic strategy and the higher mean residual SD of the GATE-i strategy compared to the conventional strategy.

The differences in stimulus-duration should be negligible as Funkhouser and Fankhauser [27] reported that for a background luminance level of 10 cd/m^2 the temporal summation is essentially complete for stimuli of 100 ms duration. However, in a study presented by Pennebaker et al., [61] examinations conducted with a stimulus duration of 200 ms showed a mean threshold level 0.9 dB higher compared to those with a stimulus of 100 ms. The comparatively higher DLS threshold values of the GATE-i strategy could therefore be partly influenced by the higher stimulus-duration used with the GATE-i strategy (200 ms compared to 100 ms with the conventional and the dynamic strategies).

Despite the dimmer background luminance levels used in the dynamic strategy, there were only minor differences in the shape of the HOV between the dynamic and the conventional strategies. Aulhorn et al. [2] found, that the slope of the HOV was lower and the achieved DLS values were higher with a background luminance of 1.27 cd/m^2 than with a background level of 10 cd/m^2. The O900 uses slightly bluish LED light sources for both background illumination and stimulus presentation, which might have affected the shape of the HOV due to a shift within the spectral sensitivity distribution, compared to conventional illumination techniques using halogen light sources.

A major factor influencing thresholds and residual SDs is the way a strategy estimates the thresholds. Glass et al. [30] showed in a simulation with FASTPAC (see above) and the conventional strategy, that positive starting deviations (difference between starting value and actual threshold) lead to positive threshold errors (difference between estimated threshold and actual threshold) and vice versa. A possible explanation for this observance is that each stimulus response has a given probability for a false answer. In approaching the actual threshold from one direction, such a false answer would lead to a reversal in the strategie`s algorithm and therefore lead to an ealier interruption with a threshold dislocated in the same direction as the starting deviation. Additionally, fluctuations of the determined thresholds would increase with increasing absolute starting deviations. The seed points of the GATE-i strategy might have been further away from the actual thresholds as compared to the other two strategies and therefore led to the slightly higher DLS values. Further studies with GATE, which applies results of the first examination as seeding points instead of referring to age-related normal values as in GATE-i, will show whether the residual SD will decrease.

Furthermore, a strategy which poses fewer questions than another one will most likely result in a higher residual SD. The GATE-i strategy asks less questions than the conventional strategy and stops the bracketing procedure at an earlier level. This is a major reason for the slightly higher mean residual SD compared to the conventional strategy. As the GATE-i strategy poses more questions than the dynamic strategy, we expected the GATE-i strategy to present a lower residual SD than the dynamic strategy. The reason for the difference is therefore not obvious.

Hermann et al. [37] presented a mean residual SD within the 30° VF of less than 1.75 dB (exact results were not reported), whereas the mean residual SD of all three strategies in this study within 30° were slightly above 2 dB (conventional strategy: 2.13 dB, dynamic strategy: 2.17 dB, GATE-i strategy: 2.23 dB). One reason for this may be that Hermann et al. only allowed 20% of false catch trials whereas in this study 30% were allowed. This limit was decided upon as previous studies have shown that with a 30% or 33% cut off for FP and FN no more than 4 or 5% of normal subjects must be excluded. [15,43,46,57,72] However, Vingrys and Demirel [70] suggested that only investigations with a false-response rate of less than 20% should be considered reliable. Moreover, Hermann et al. [37] only conducted one examination with each subject. As our aim was also to compare three strategies we performed three examinations on the same day. This might have led to an increase of the mean residual SD due to fatigue.

There is no information in literature about the mean SD computed from residuals in a 80° VF.

Model

Smooth models for the normal HOV within 30° eccentricity were first introduced by Schwabe et al. [68] in 2001. This enables attainment of the normal value and the p-value for any individual test location and is therefore an essential prerequesite for creating optional test point arrangements or local condensation of test locations in regions of interest, for example in glaucomatous retinal nerve fibre loss. [65]

However, there are numerous examples where the region of interest has to be expanded to the whole 80° VF, i.e. for an early diagnosis of tapetoretinal degenerations, in follow-up investigations of glaucoma patients at an advanced stage, in many neuro-ophthalmic diseases affecting the visual pathway and in therapy studies about drugs influencing the VF like vigabatrin. Therefore, normative data for the 80° VF and a smooth model for this region are presented in this paper.

The fit of the model used is better than that of previous models: Schwabe et al. [68] achieved R^2 = 0.67 and Lorch et al. [52] R^2 = 0.50 for the Twinfield perimeter and R^2 = 0.57 for the Humphrey Field Analyzer. These models were fitted only to the 30° VF, whereas our model extends up to 56° nasally, 80° temporally, 40° superiorly and 62° inferiorly. Expected mean DLS values have a wider range in the 80° VF by design. These large and easy to explain differences allow for a better R^2. Additionally, our model had more terms than those for 30° VFs.

Asymmetry

Previous studies suggested, that the DLS is higher in the nasal part of the VF within 20° eccentricity whereas the situation is reversed at higher eccentricities. [37,52] Our study confirms these results with all three strategies and extends these findings up to 80° eccentricity. Beyond 20° eccentricity, we found a greater drop of the DLS in the nasal part of the VF compared to the temporal part.

Dietrich et al. [21] claimed, that for ten-year-olds the sensitivity of the temporal hemifield is higher than the sensitivity of the nasal hemifield. For subjects at the age of approximately 40 years they found the situation to be reversed. In contrast to this study they did not calculate a mathematical model and compare the sensitivity along the meridians but determined the mean sensitivity of each subject for each hemifield. Therefore, the results of this study are not directly comparable to theirs.

Several authors reported sensitivity to be lower in the superior hemifield than in the inferior one. [6,21,22,35,44,52,77] This study confirms these results for all age decades and extends these findings up to 80° eccentricity. In this study the greatest drop of DLS values occurred in the superior periphery. Katz and Sommer [44] also reported that the greatest drop occurs in the superior periphery, but they were refering to a 30° VF. As an explanation for this asymmetry they proposed that, while the subject is blinking, upper lids move down more than lower eyelids move up. As the O900 stopped the examination procedure when the subject closed the eye, this explanation seems unlikely. Hermann et al. suggested as explanation for this phenomenon the greater luminance of the sky above the horizon which causes a greater adaption in the upper VF and eye lid artifacts. Curcio et al. [17] reported a higher ganglion cell density in the superior part of the retina than in the inferior one.

We are in agreement with several authors who reported a greater drop of the superior VF with age. [21,33,37,44] However, none of them investigated the whole 80° VF.

Ageing

It is generally known that DLS values decrease with age. Reasons might be age-related reductions of pupil size, changes of the lens densitiy with age, [16,18] a decrease of the axonal count of the human optic nerve, [3] a decline in mean fiber diameter, [62] a reduction in photoreceptors density [17,28,29,54] and a decrease of the neuron population density in the visual cortex. [20] Johnson et al. [42] suggested that neural losses are the main reason for age-related changes of the VF sensitivity.

Previous studies did not agree in the manner in which DLS decreases: Some authors claim that local DLS values decrease with age in a linear way. [22,23,33,35,40,59,77] Others state that local DLS values decrease in a non-linear way and also decrease more rapidly at older ages. [19,37,39,43,49,50,52] Our results confirm a non-linear pattern of ageing. Hermann et al. [37] reported, that some of the studies which found a linear sensitivity decrease showed some deficiencies in the study design. Lachenmayr et al. [49] observed, that studies which found a non-linear decrease in DLS had stricter inclusion criteria. Gartner and Henkind [29] reported a displacement of nuclei from the outer nuclear layer into the outer plexiform layer, which increased after the age of 30 years, and a displacement of nuclei from the outer nuclear layer to the layer of rods and cones which increased considerably after 40 years of age. Gao and Hollyfield [28] reported that rods and cells in the ganglion cell layer show nonuniform rate decreases with age with a faster rate of rod an ganglion cell loss between the second and fourth decades. Devaney and Johnson [20] stated that the population density of neurons in the visual cortex decreases mostly between the third and sixth decade.

The findings presented here are in agreement with Jaffe et al., [40] Haas et al., [33] Okuyama et al., [59] Zulauf et al. [78] and Heijl et al. [35] who reported that sensitivity decrement with age is eccentricity dependent. Haas et al. [33] and Heijl et al. [35] reported the HOV becoming steeper with age, whereas Brenton and Phelps [13] stated that the slope of the HOV remains the same. This study adds confirmation that the slope increaes with age and extends these findings up to 80° eccentricity. Reasons for the steepening of the HOV could be the narrowing of the pupils with age as well as opacities concerning the rim of the lens. Gao and Hollyfield, [28] Gartner and Henkind [29] and Curcio et al. [17] reported a more noticeable loss of rods than cones with age and a higher loss of photoreceptors in the periphery compared to the fovea. Wohlrab et al. [76] explained this phenomenon is due to a reduction in blood supply to the retina with age, in which the peripheral part of the retina is more affected.

Some authors reported a higher influence of age on the superior part of the VF. [33,44,77] In the 25° VF we found the superior and nasal part of the VF only slightly and likely not significantly more affected by age, but in the 60° VF this phenomenon was obvious and more pronounced. Lorch et al. [52] could not detect a difference in the effect of ageing between the superior and inferior part of the 30°

VF. The detected asymmetry of ageing in this study can at least partly be explained by lid effects. Furthermore, an asymmetric constitution of the retina, different illumination conditions of the hemiretinae and differences in the distribution of receptor and ganglion cells are reasonable explanations.

The conventional and the dynamic strategies show similar results. The GATE-i strategy presents a smaller difference than the other two strategies, but the greatest decrease in the VF is still in the nasal and superior periphery.

Retest reliability

Measurements of the SF and LF have been a part of VF diagnostics for more than two decades. [4,13,14,25] SF functions are a part of reliability measurements and characterize the patient's consistency during the test period. SF is usually approximately 1.5 dB and increases to 2.5 dB or more in case of VF defects. [75] Our data are in close agreement with previous results.

For follow-up evaluation knowledge of the long-term variabiliy (long-term fluctuation) is essential. Variability of the DLS values between two measurements is known to be considerable even in normal VFs, and has been shown to increase for example in glaucoma patients even before VF loss. [4,25] The LF of test subjects was highest with the GATE-i strategy and lowest with the dynamic strategy, but the differences were no greater than 0.51 dB. As the dynamic strategy has the lowest test duration this might have caused the corresponding lowest LF. However, it is not obvious why the GATE-i strategy has the highest LF. All strategies showed higher LF values than earlier reported normal subject LF values for Octopus perimeters which ranged from 1.6±0.5 dB to 1.97±0.99 dB. [12,48] However, our values are measured from the entire 80° VF, and the fluctuation is known to increase towards the periphery, as mentioned earlier. [35,45,51,60,64,77] The SD for the LF was quite high in our study because of the small number of subjects who participated in the follow-up study with three sessions.

Earlier studies showed, that SITA Standard has a similar or even lower test-retest variability than the Full Threshold strategy in normal subjects [1,10] as well as in glaucomatous patients. [7] Therefore, every new fast strategy, such as the GATE-i strategy, must be compared with this outcome as well. In this study, with normal subjects, the GATE-i strategy has a slightly higher LF than the conventional strategy. Further studies will have to analyze the LF of patients with the GATE-i strategy.

Bengtsson and Heijl reported, that in patients with glaucoma there were no significant differences in reproducibility between FASTPAC and Full Threshold. [8] A rise in mean DLS values could be seen between the first and the second session with the GATE-i strategy, and between the second and the third session with the dynamic strategy. With the conventional strategy, the lowest DLS values were measured during the second session, and during the third session mean DLS rose to slightly higher values than during the first session. It has been shown, that perimetric experience improves the test results. [36] A clinician must observe the possibility of an increased number of depressed test locations in the first VF examination. GATE-i strategy uses a constant stimulus interval, and is possibly therefore easier to learn, evoking an immediate learning effect.

Number of presented stimuli

As expected, the conventional strategy presented the highest number of stimuli both in the centre (within 30°) and in the periphery. In the entire 80° VF, the dynamic strategy presented fewer stimuli than the GATE-i strategy did, but with respect to the results for the VF between 30° and 80° the GATE-i strategy presented less stimuli than the dynamic strateagy.

Results concerning the mean number of stimuli per localisation for the conventional strategy in this study are in good concordance with those found in literature (4.7 stimuli per localisation in our study, Weber: 5.12 per localisation, [73] Bebie et al.: 4-5 stimuli per localisation. [5])

Weber [73] stated, that the dynamic strategy presents on average 2.24 stimuli per localisation. In our study, the dynamic strategy presented 3.4 stimuli per localisation (mean) in the 80° VF, and 2.6 stimuli (mean) in the 30° VF. It is assumed that Weber only tested localisations within 30° eccentricity. The reason for the lower number of stimuli may be because he only analyzed the results of one young subject.

SITA Standard reduced the number of stimuli presented by 29% compared to the Full Threshold strategy [10,11] whereas in our study the dynamic strategy presented 42.9% and the GATE-i strategy 19.4% less stimuli within the 30° VF than the conventional strategy did. Bengtsson et al. reported that FASTPAC reduced the number of presented stimuli as compared to Full Threshold by 40.6%, [10] Flanagan et al. stated 42.3%. [26] O`Brien et al. presented a reduction of stimuli of 34.2% in glaucomatous patients. [58]

There is no information in the literature about the mean number of stimuli presented with the TOP-strategy. However, Morales et al. did report, that TOP needs one quarter of the investigation time conventional staircase threshold procedures need, this is a reduction of 75%. [56]

Comparison of the O900 with the O101

On average the O101 shows only slightly higher values than the O900. This difference is below the measured LF between the first and second investigation of this study obtained with the O900 and therefore does not appear to be relevant. Differences between the two instruments such as cupola radius, light source and light temperature of background luminance (the background of the O101 has a yellowish colour while the O900 is somewhat blue) do not seem to have a relevant effect. There are two conspicuous points in the temporal hemifield (68°/-38° and 80°/0°) where the O900 shows values which are more than 5 dB higher than the O101. Observing the responses of each subject separately, it was noted that in the O101 eleven subjects did not perceive the spot 68°/-38° and 13 did not respond to 80°/0° at all, whereas in the O900 only one person did not notice the spot 68°/-38° and all of them were able to see 80°/0°. We assume that the lense holder of the O101 in its "testing position" obscured vision for those subjects as it is attached in the cupola *on the right side* of the subjects and has to be flapped in when investigating the 30° VF. In contrast, the lense holder of the O900 is located *below* the subject's face when not needed and therefore does not disturb the investigation of the 80° VF.

Furthermore, there are six spots in the upper most and nasal part of the VF, where the O101 shows values more than 1.5 dB higher than the O900. Inhomogeneity of the background luminances was assumed to be a reason, but as the measured inhomogeneities in both perimeters (see “Technical data”) do not match with the peculiar spots, this cannot explain the discrepencies.

Another explanation might be the different design of the chin- and forehead-rest of the two perimeters. In the O900 instrument used for the study, several subjects tended to move his/ her head backward due to an inadequate position of the forehead rest. Artefacts produced by the lense holder might therefore be the reason. In the current O900-model, the forehead rest was therefore slightly modified.

5. Conclusion

The development of a smooth mathematical model for the three strategies, the conventional, the dynamic and the GATE-i strategies, allows for the prediction of age-corrected normal DLS values for any stimulus location within the 80° VF. With respect to residual SD, mean DLS values and SF and LF, results of the three strategies were very similar. The dynamic strategy reduced the number of presented stimuli as compared to the conventional strategy by 27.7%, the GATE-i strategy by 17.6%. Local DLS values of the O900 and the O101 perimeters differ only slightly for the GATE-i strategy.

6. Summary

Purpose: **1.** To create a model describing age-corrected normal values for the entire 80° visual field (VF) measured with the Octopus 900 (O900) perimeter, **2.** to compare three threshold estimating strategies: conventional (4-2-1), dynamic and German Adaptive Threshold Estimation (GATE-i) and **3.** to compare local differential luminal sensitivity (DLS) values obtained with the GATE-i strategy on both, the O900 and the Octopus 101 (O101) perimeters.

Methods: 81 ophthalmologically healthy subjects between 10 and 79 years of age were examined with the O900 perimeter within 80° eccentricity (86 stimulus locations) using the three different strategies in a randomised order. 16 stimulus locations were measured twice during one examination in both conventional and dynamic strategies to assess the short-term fluctuation (SF). To measure the long-term fluctuation (LF), 14 subjects were examined on two further appointments. 24 subjects were examined with the GATE-i strategy on both the O900 and the O101 perimeters.

Results: With the dynamic strategy local DLS values were 0.21 dB (mean) higher, with the GATE-i strategy 0.98 dB (mean) higher than with the conventional strategy. A smooth mathematical model for each strategy was achieved. Model fit was nearly identical for the conventional (R^2 = 0.75), the dynamic (R^2 = 0.76), and the GATE-i (R^2 = 0.72) strategies. The effect of age on the DLS asymmetry in the VF increased with eccentricity. The greatest decrease of the VF with eccentricity occured in the superior hemifield. The decrease from the centre to 60° eccentricity was for 45-year-olds 24.10 / 23.00 / 24.48 dB (conventional / dynamic / GATE-i strategies). The greatest drops of DLS values with age occured in the nasal and superior periphery. At 60° the nasal DLS was estimated to be 7.91 / 8.13 / 6.25 dB (conv. / dyn. / GATE-i strategy) higher in 15-year-olds than in 75-year-olds. At 60° in the superior hemifield the DLS was estimated to be 7.98 / 8.45 / 6.53 dB (conv. / dyn. / GATE-i strategy) higher in 15-year-olds than in 75-year-olds. Within the 80° VF residual standard deviation (SD) was 2.36 dB for the conventional strategy, 2.30 dB for the dynamic strategy and 2.52 dB for the GATE-i strategy. SF was 1.43 dB for the conventional strategy and 1.51 dB for the dynamic strategy. For the first retest, LF was 2.34 dB for the conventional, 2.22 dB for the dynamic and

2.82 dB for the GATE-i strategy, respectively. For the second retest, LF was 2.25 dB for the conventional, 2.11 dB for the dynamic and 2.53 dB for the GATE-i strategy. The number of stimuli presented per localisation (mean) was 4.7 for the conventional strategy, 3.4 for the dynamic and 3.9 for the GATE-i strategy. Local DLS values with the GATE-i strategy on both perimeters were similar (mean difference: 0.27 dB).

Conclusion: A smooth mathematical model for all three strategies for the 80° VF was developed and described, model fit was satisfactory. Mean DLS values, residual SD, SF and LF of conventional and dynamic strategies were nearly identical. The GATE-i strategy showed slightly higher mean DLS values and a somewhat higher residual SD and LF. The conventional strategy needed the most repetitions of stimuli, while the dynamic strategy required the fewest. Local DLS values of the O900 and O101 perimeters differed only slightly for the GATE-i strategy.

7. Zusammenfassung

Ziele: 1. Entwurf eines mathematischen Modells, das die mit dem Perimeter "Octopus 900" (O900) gemessenen alterskorrigierten Normwerte für das gesamte 80°-Gesichtsfeld beschreibt, **2.** Vergleich von drei verschiedenen schwellenbestimmenden Strategien: konventionelle (4-2-1), dynamische und GATE-i (**G**erman **A**daptive **T**hreshold **E**stimation **- i**nitial) Strategie, auch im Hinblick auf Retest-Reliabilität, und **3.** Vergleich der mit der GATE-i Strategie ermittelten lokalen Lichtunterschiedsempfindlichkeiten (LUE) des O900 mit den LUE-Normwerten des älteren Octopus-101- Perimeters (O101).

Methoden: 81 gesunde Probanden (Alter: 10 - 79 Jahre) wurden mit dem O900 innerhalb einer Exzentrizität von 80° (Prüfpunktraster mit 86 Testpunkten) mit allen drei Strategien in randomisierter Reihenfolge untersucht. An 16 Stimuluslokalisationen wurde die LUE während der Untersuchungen mit der konventionellen und der dynamischen Strategie jeweils zu zwei Zeitpunkten bestimmt, um zusätzlich die Kurzzeit-Retest-Reliabilität zu ermitteln. Um die Langzeit-Retest-Reliabilität zu bestimmen, wurden 14 Probanden an zwei weiteren Terminen mit allen drei Strategien nochmals untersucht. 24 Probanden wurden an einem weiteren Termin mit der GATE-i Strategie sowohl am O900 als auch am O101 untersucht.

Ergebnisse: Mit der dynamischen Strategie waren die LUE-Werte im Mittel 0,21 dB höher, mit der GATE-i Strategie 0,98 dB höher als mit der konventionellen Strategie. Ein geglättetes mathematisches Modell wurde für jede Strategie entworfen, mit dem man die LUE für jeden beliebigen Ort des Gesichtsfeldes berechnen kann. Die Güte der Anpassung war annähernd gleich: $R^2 = 0,75$ für die konventionelle, $R^2 = 0,76$ für die dynamische und $R^2 = 0,72$ für die GATE-i Strategie. Die mittlere Standardabweichung der Residuen betrug 2,36 / 2,30 / 2,52 dB (konv. / dyn. / GATE-i Strategie). Der stärkste Abfall des Gesichtsfeldes *mit der Exzentrizität* trat in der oberen Gesichtsfeldhälfte auf. Der größte Abfall der LUE *mit dem Alter* trat in der nasalen und oberen Peripherie auf. Die Kurzzeit-Retest-Reliabilität lag bei 1,43 dB für die konventionelle und 1,51 dB für die dynamische Strategie. Die mittlere Langzeit-Retest-Reliabilität betrug 2,30 / 2,17 / 2,68 dB (konv. / dyn. / GATE-i Strategie). Die mittlere Anzahl der präsentierten

Stimuli zur Schwellenbestimmung pro Lokalisation war 4,7 / 3,4 / 3,9 (konv. / dyn. / GATE-i Strategie). Die LUE-Werte der GATE-i Strategie an beiden Perimetern unterschieden sich nur minimal (mittlere Differenz: 0,27 dB).

Schlussfolgerung: Das mathematische Modell für die Gesichtsfeldberge ist zufrieden stellend. Mittlere LUE-Werte, die Standardabweichung der Residuen sowie die Kurz- und Langzeit-Retest-Reliabilität waren annähernd identisch für die konventionelle und die dynamische Strategie: die GATE-i Strategie zeigte geringfügig höhere mittlere LUE-Werte, eine etwas höhere Standardabweichung der Residuen und eine geringfügig höhere Langzeit-Retest-Reliabilität. Die konventionelle Strategie benötigte die meiste Anzahl an Stimuli, die dynamische Strategie die geringste. Die lokalen LUE-Werte der GATE-i Strategie des O900 und des O101 unterschieden sich nur minimal.

8. Tables and figures

TABLE 1. Main properties of the two perimeters: the Octopus 900 and its precursor, the Octopus 101.

	Octopus 900 	Octopus 101 
Cupola radius	30 cm	42.5 cm
Light source	white LED light sources	halogen light sources
Measurement range	0…47 dB	0…47 dB
Max. stimulus intensity	1910 cd/m^2 (6000 asb)	1910 cd/m^2 (6000 asb)
Background intensity	4 asb (1.27 cd/m^2), 31.4 asb (10cd/m^2)	4 asb (1.27 cd/m^2), 31.4 asb (10cd/m^2)

TABLE 2. Properties of the three perimetric strategies.

Strategy	Background luminance [cd/m^2]	Stimulus-duration [msec]	Inter-stimulus interval [msec]
Conventional	10	100	Adaptive (1500-4000)
Dynamic	1.27	100	Adaptive (1500-4000)
GATE-i	10	200	1200

TABLE 3. Number, gender ratio, and mean age (per decade of age) of the participants in each cohort. SD standard deviation.

Age Group [yrs]	No. of Participants	Ratio (Male:Female)	Mean Age (SD; Range), [yrs]
10-19	12	6:6	15.5 (2.39; 10.2-19.1)
20-29	12	5:7	25.1 (1.89; 21.9-27.8)
30-39	13	4:9	36.0 (3.03; 30.4-39.9)
40-49	12	6:6	45.7 (2.73; 41.1-49.7)
50-59	10	3:7	55.6 (2.70; 51.4-59.8)
60-69	11	6:5	64.1 (2.02; 61.2-67.3)
70-79	11	6:5	74.8 (2.67; 70.0-78.6)

TABLE 4. Mean differences of the three strategies in the 80° visual field for each age-group.

Age [yrs]	Mean of GATE-i – conventional strategy [dB]	Mean of GATE-i – dynamic strategy [dB]	Mean of dynamic strategy – conventional strategy [dB]
10-19	0.57	0.50	0.06
20-29	0.84	0.72	0.12
30-39	0.83	0.56	0.27
40-49	1.15	0.69	0.47
50-59	1.09	1.11	-0.02
60-69	1.28	0.96	0.31
70-79	1.15	0.95	0.19

TABLE 5. Goodness of fit of the hill of vision by strategy. R^2 denotes the coefficient of determination, SD standard deviation, VF visual field. Ten test-locations in the upper most and nasal part of the visual field (see Fig.2 and Fig.7) were defined as "rim". Their variance was modeled to be larger – as expected – while their mean differential luminance sensitivity values were fitted with the smooth model.

Strategy	R^2	Residual SD in the 30° VF [dB]	Residual SD in the 30°-80° VF without rim [dB]	Residual SD in the 80° VF without rim [dB]	Residual SD rim [dB]
Conventional	0.75	2.13	2.79	2.36	4.85
Dynamic	0.76	2.17	2.56	2.30	5.16
GATE-i	0.72	2.23	3.05	2.52	4.99

TABLE 6. Mean of differences (mean DIFF) and long-term fluctuations (LF) of local differential luminance sensitivity (DLS) values between the initial examinations and second examinations (2.-1. session) and between second and third examinations (3.-2. session) for 14 normal subjects for all three strategies.

	2.-1. session		3.-2. session		
Strategy	Mean DIFF [dB]	LF [dB]	Mean DIFF [dB]	LF [dB]	Mean LF [dB]
Conventional	-0.10	2.34	0.25	2.25	2.30
Dynamic	0.05	2.22	0.36	2.11	2.17
GATE-i	0.48	2.82	0.02	2.53	2.68

TABLE 7. Mean number of stimuli and mean number of stimuli *per localisation* (SPL) with standard deviation in brackets for different parts of the visual field (VF).

Strategy	Number of stimuli in the 30° VF	Number of stimuli in the 30°-80° VF	Number of stimuli in the whole 80° VF	SPL in the 30° VF	SPL in the 30°-80° VF	SPL in the whole 80° VF
Conventional	237.4 (25.8)	172.4 (12.7)	409.8 (33.4)	4.6 (0.5)	5.1 (0.4)	4.7 (0.4)
Dynamic	135.6 (8.6)	164.5 (9.1)	300.1 (15.0)	2.6 (0.2)	4.8 (0.3)	3.4 (0.2)
GATE-i	191.3 (15.3)	146.5 (22.4)	337.8 (33.5)	3.7 (0.3)	4.3 (0.7)	3.9 (0.3)

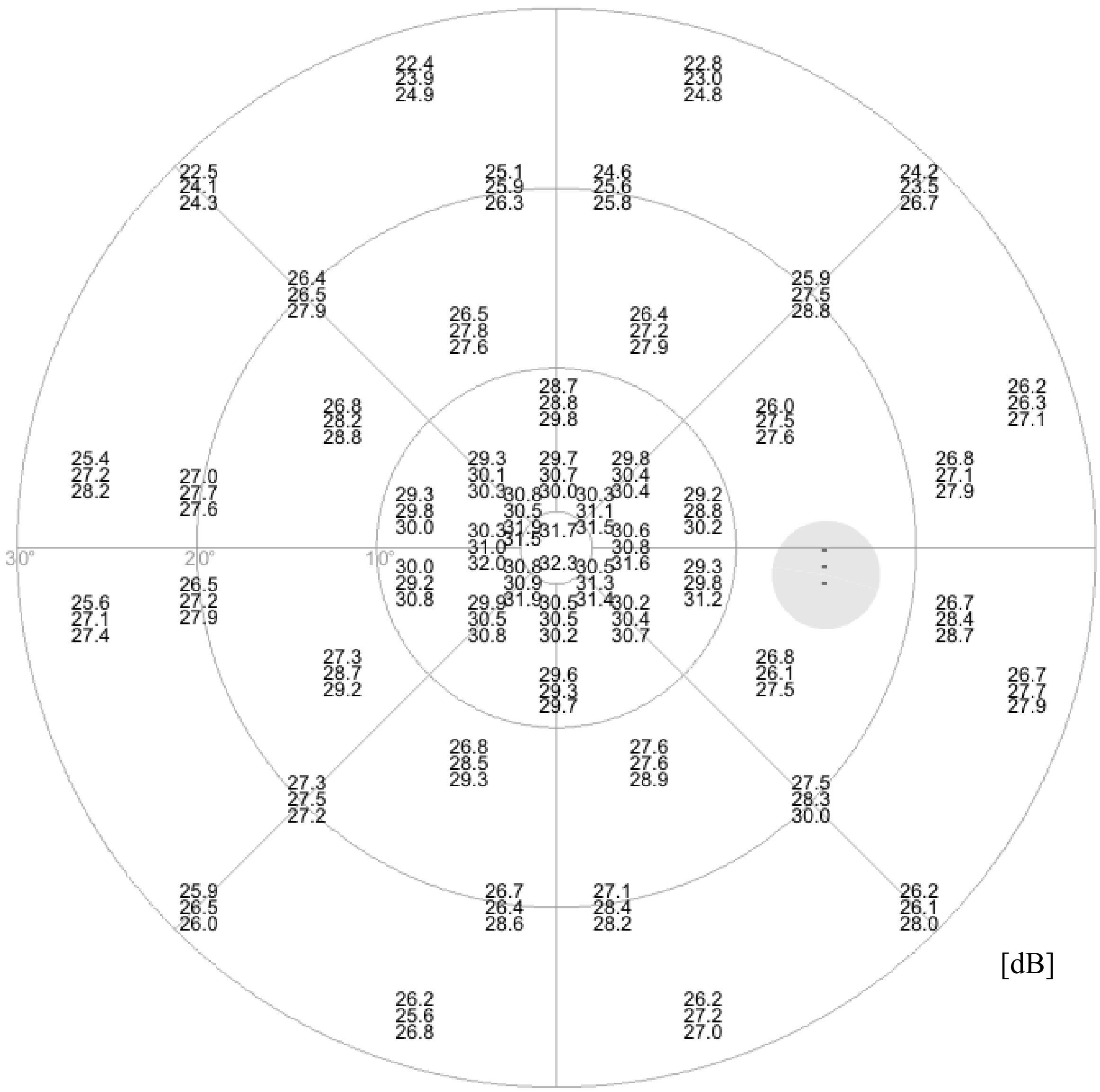

FIGURE 1. Mean local thresholds [dB] of the *30° visual field* for twelve subjects between 40 and 49 years of age for all three strategies (upper: conventional strategy, middle: dynamic strategy, bottom: GATE-i strategy).

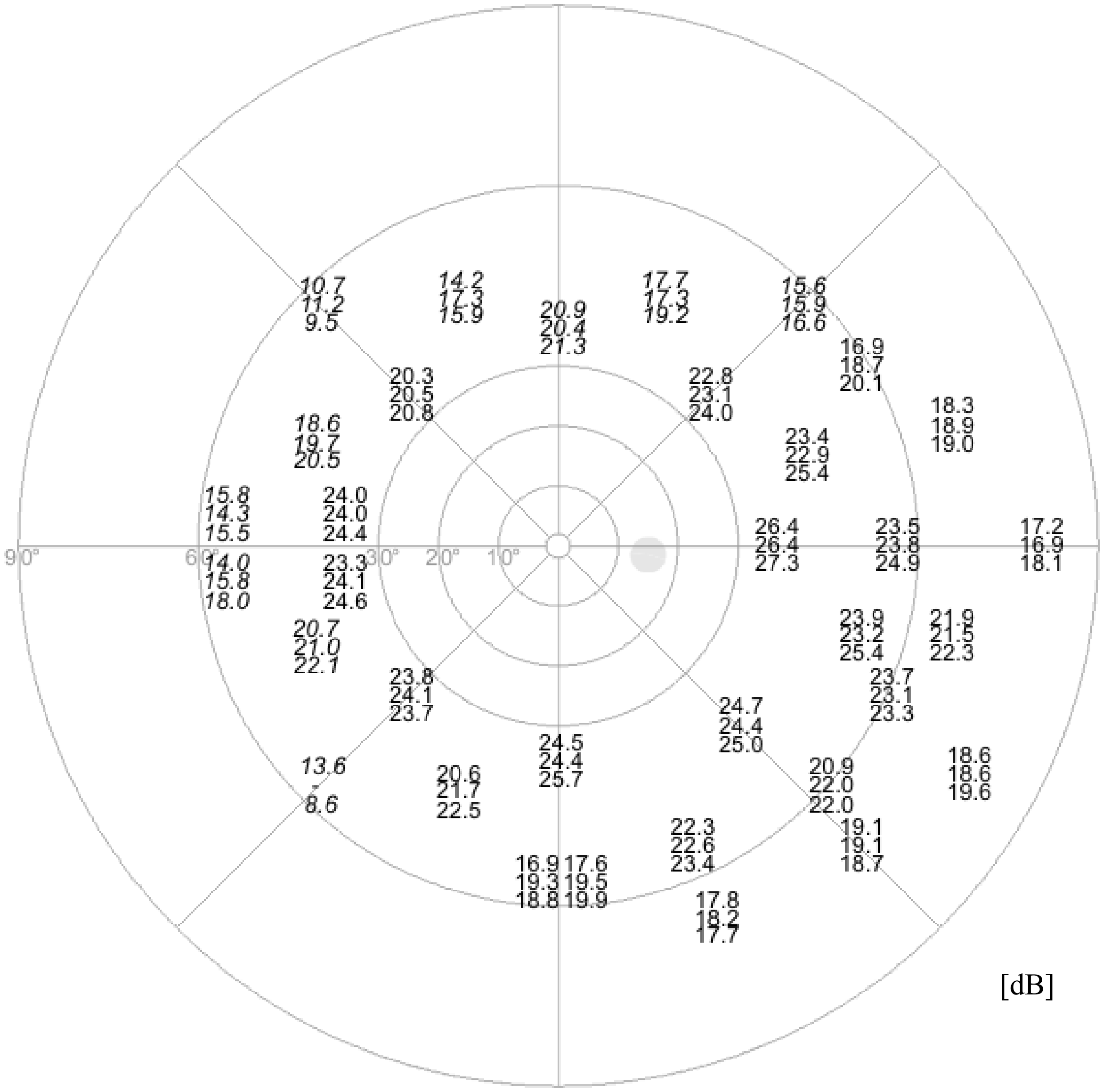

FIGURE 2. Mean local thresholds [dB] *in the 30°-80° visual field* for twelve subjects between 40 and 49 years of age for all three strategies (upper: conventional strategy, middle: dynamic strategy, bottom: GATE-i strategy). For locations defined as “rim” numbers are italicised.

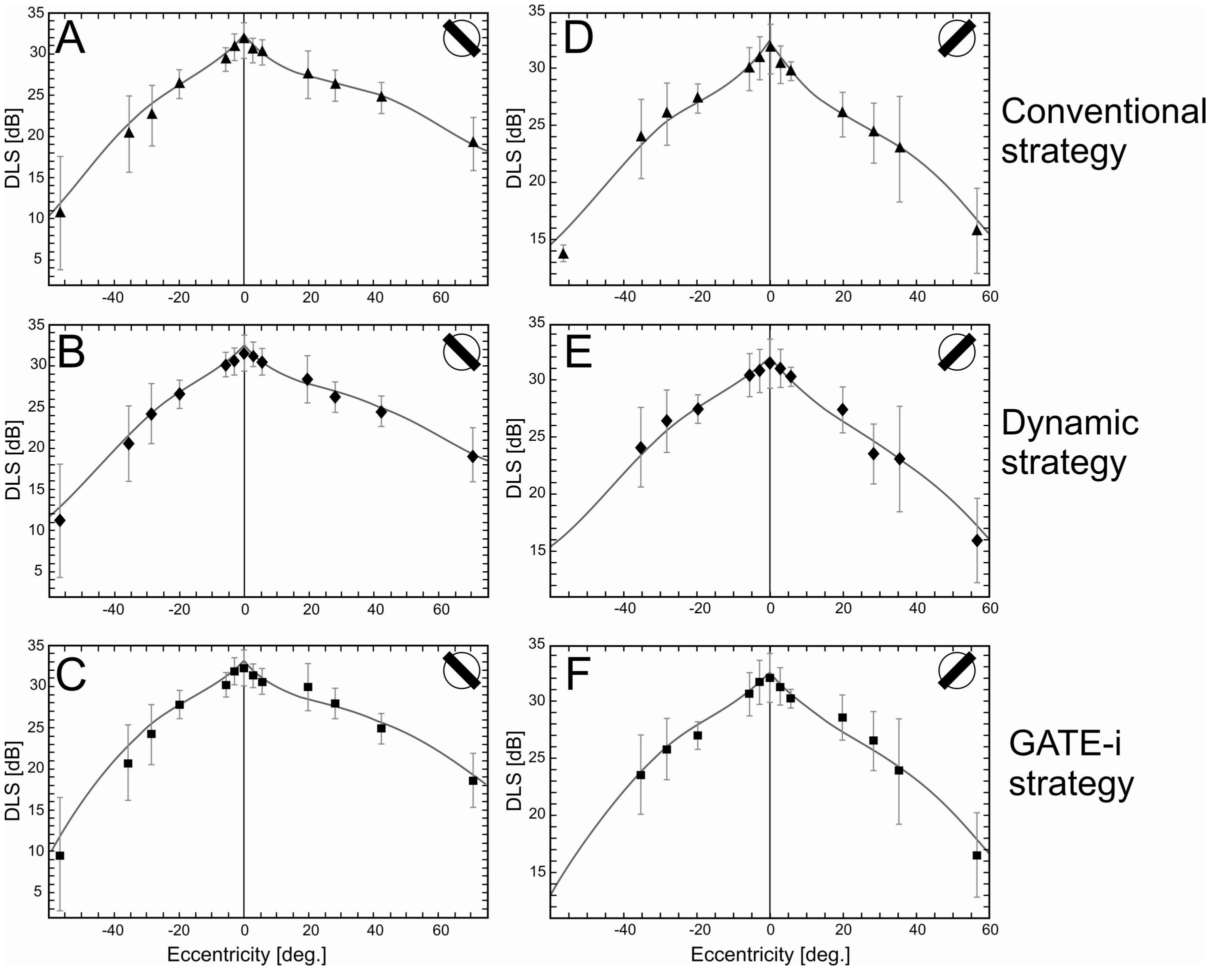

FIGURE 3. Diagonal section through the model for 45-year-old subjects. A-C: From the upper nasal to the lower temporal part of the visual field (see inserted symbol in the right upper corner of the related diagrams). D-F: From the upper temporal to the lower nasal part of the visual field (see inserted symbol in the right upper corner of the related diagrams). Symbols are means of differential luminance sensitivity values of the subjects between 40 and 49 years of age, bars indicate the standard deviation.

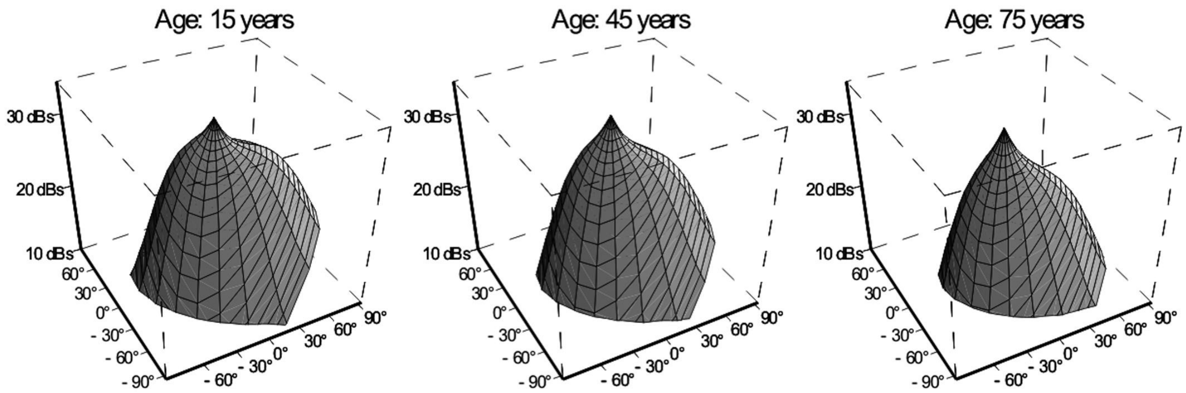

FIGURE 4. The smooth mathematical model for the GATE-i strategy for 15-year-olds, 45-year-olds and 75-year-olds.

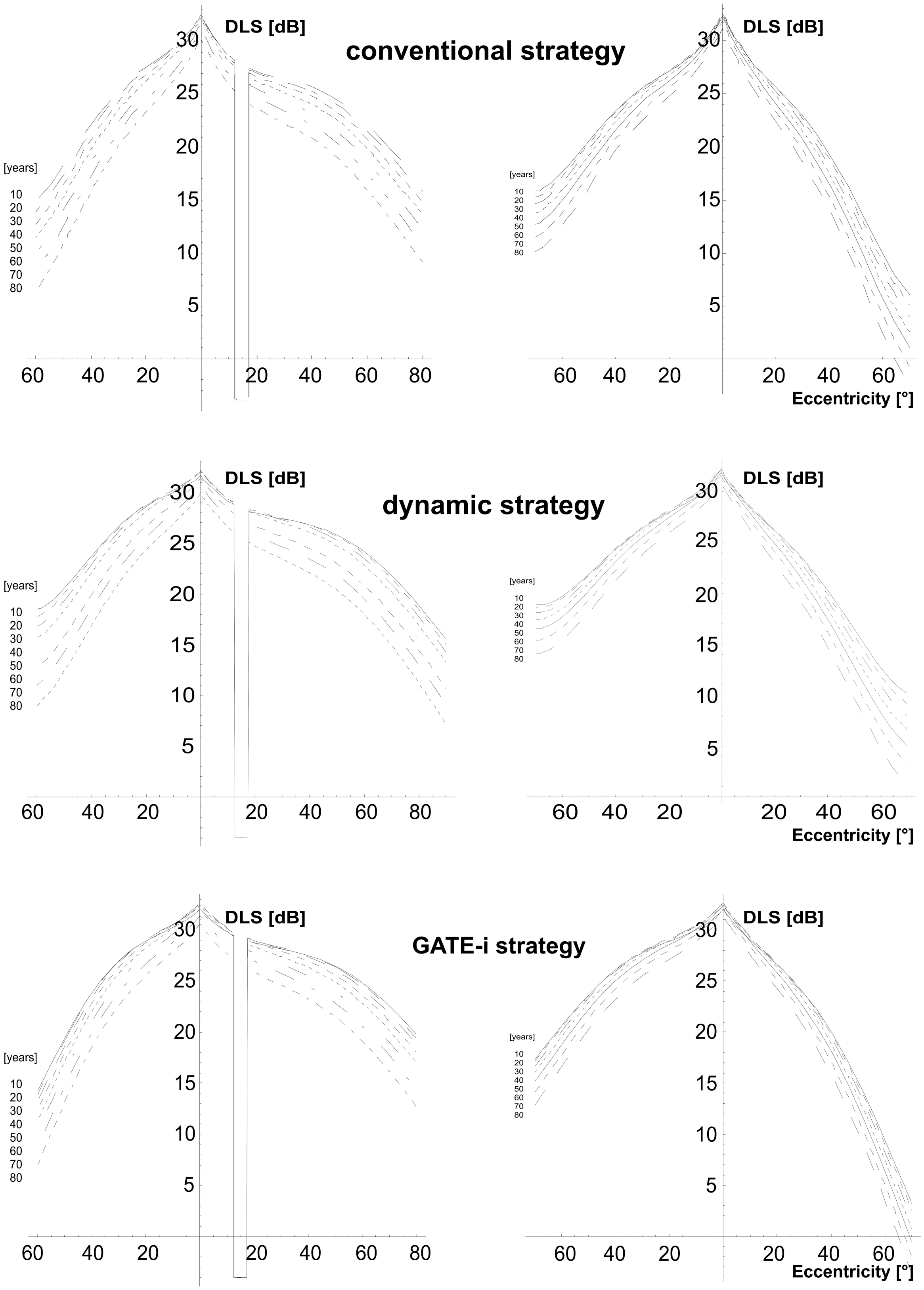

FIGURE 5. Left: Age effect of the hill of vision in the horizontile profile section (0°-180°). Right: Age effect of the hill of vision in the vertical profile section (90°-270°).

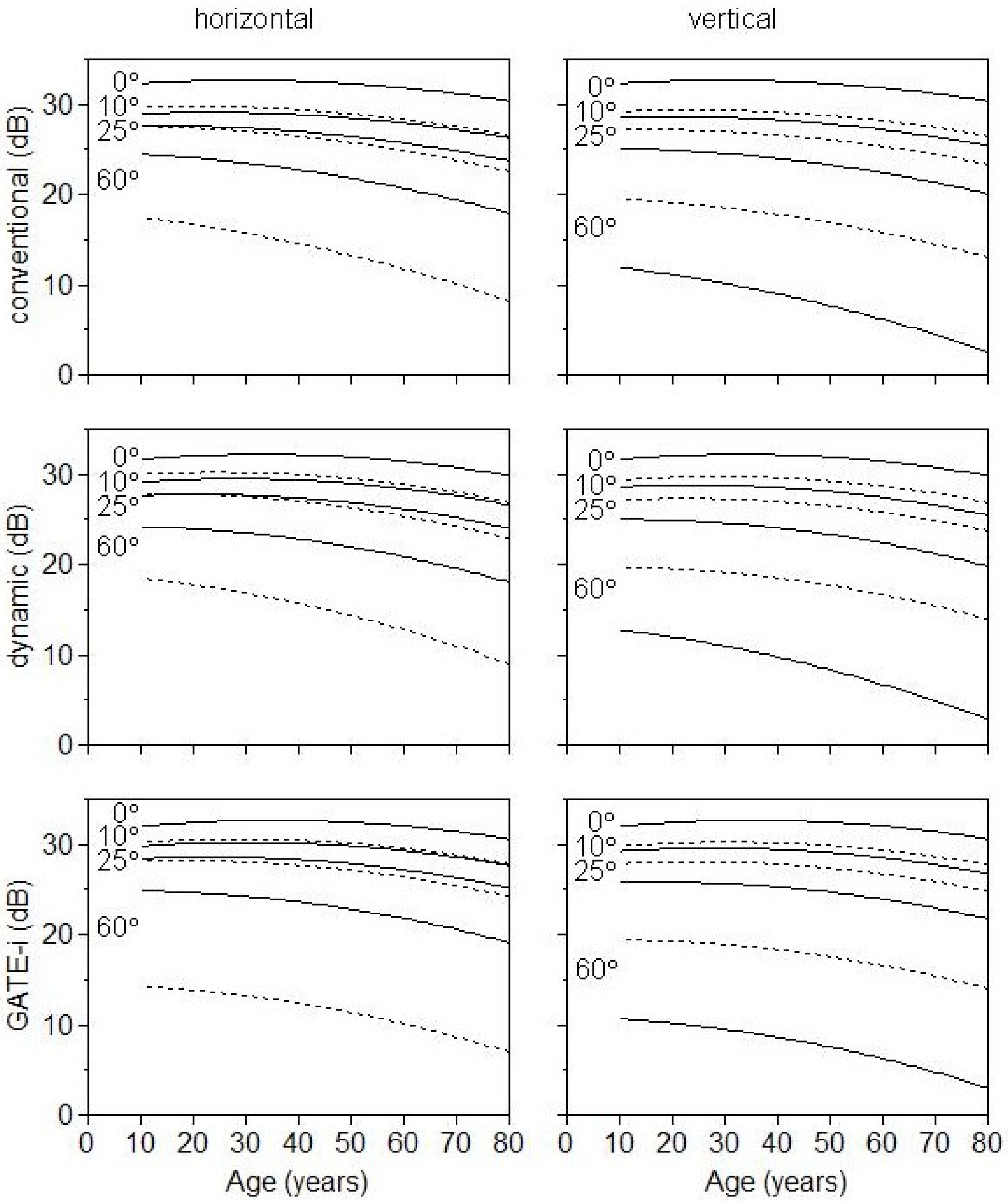

FIGURE 6. Left: Age dependence of the temporal-nasal asymmetry at 0°, 10°, 25° and 60°. Predicted differential luminance sensitivity at the horizontal meridian (0°-180°) and indicated eccentricities for the temporal (solid lines) and nasal (dotted lines) hemifields by age. Right: Age dependence of the superior-inferior asymmetry at 0°, 10°, 25° and 60°. Predicted differential luminance sensitivity at the vertical meridian (90°-270°) and indicated eccentricities for the superior (solid lines) and inferior (dotted lines) hemifields by age.

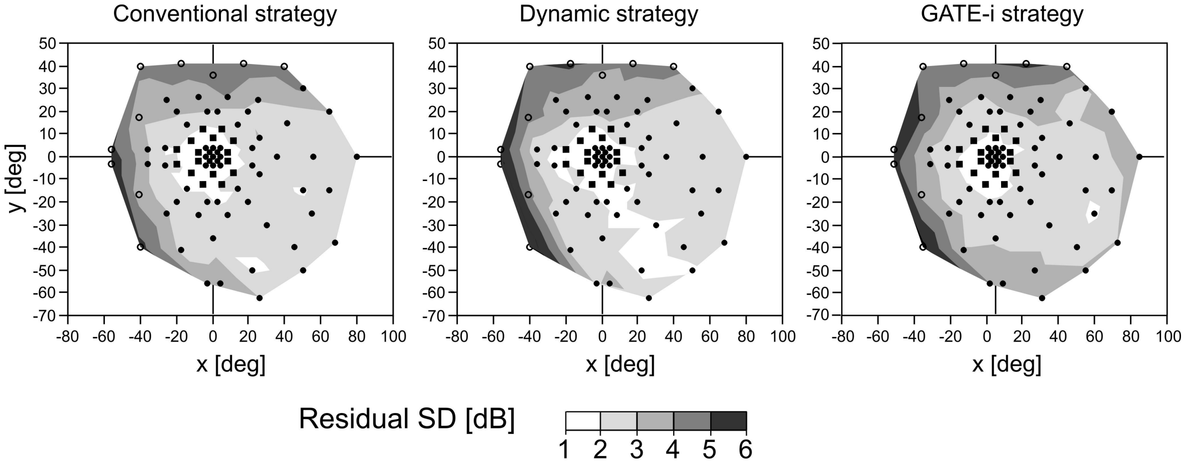

FIGURE 7. Standard deviations computed from the residuals for the conventional strategy (left), the dynamic strategy (middle) and the GATE-i strategy (right) with respect to the test point location. Square markers show the locations where the short-term fluctuation was measured. Open circles show the locations definded as “rim”.

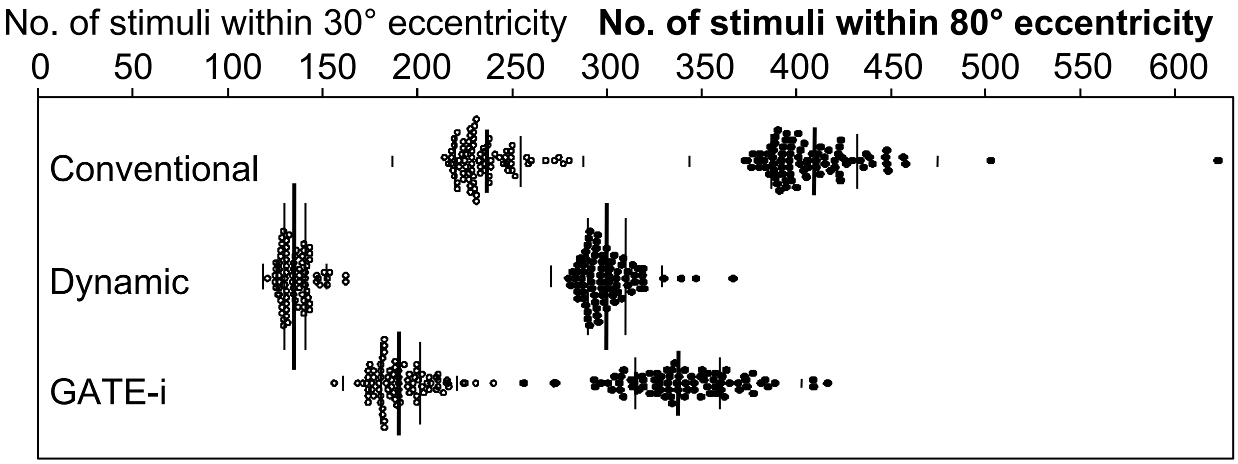

FIGURE 8. Number of stimuli needed in the central 30° visual field (circles) and for the whole visual field (dots) by strategy for 81 subjects each. Long strong bars indicate means, long thin bars quartiles, and short thin bars 2.5%-quantiles of the normal distributions with means and standard deviations estimated from the data. Stimulus types specific to examinations, e.g. catch trials, were discounted.

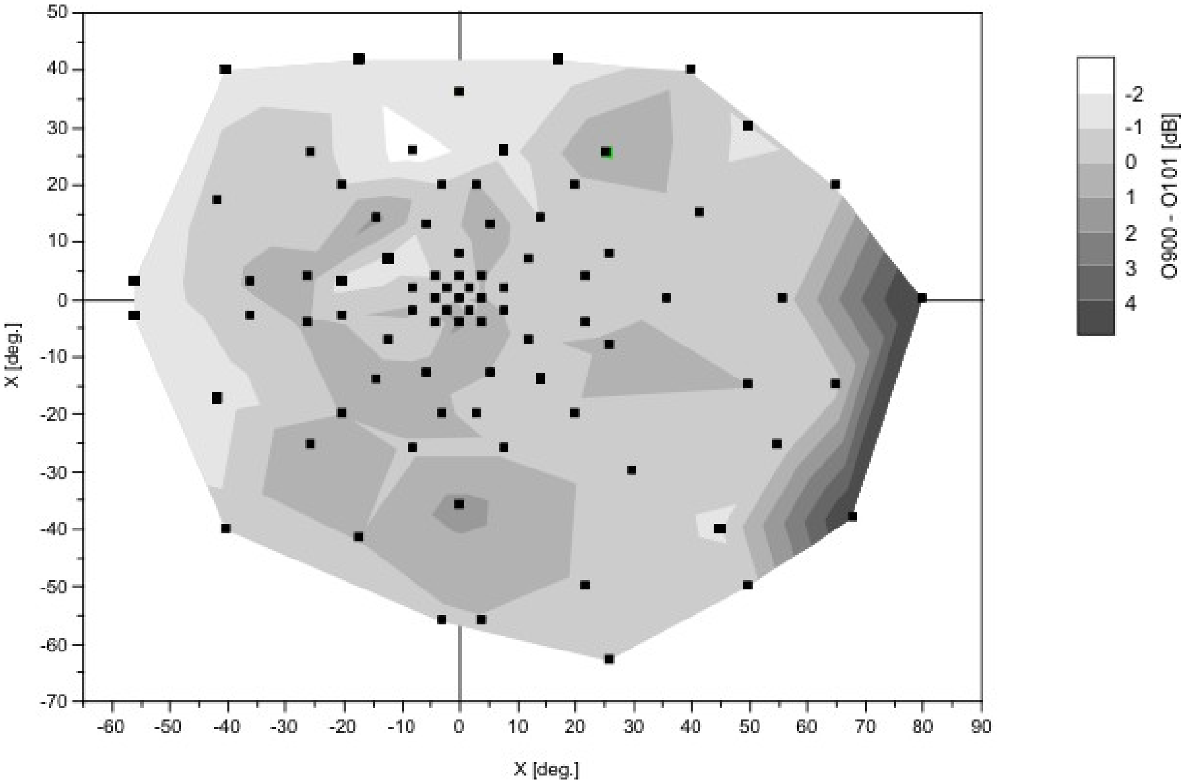

FIGURE 9. Mean differences between the Octopus 900 and the Octopus 101 [dB] for each test localisation.

9. Appendix:

Differential Luminance Sensitivity (DLS) =
31.9104058309877

$+0.05137743726682 \cdot age$
$-0.48548039398516 \cdot ecc$
$+0.01852304963376 \cdot ecc^2$
$-0.0004117636308 \cdot ecc^3$
$-0.0068022205391 \cdot ecc \cdot \sin(a)$
$-0.0487363331955 \cdot ecc \cdot \cos(a)$
$-0.0084503978843 \cdot ecc \cdot \sin(2a)$
$+0.01763334062776 \cdot ecc \cdot \cos(2a)$
$-0.0006150849904 \cdot ecc^2 \cdot \sin(a)$
$+0.00043601269742 \cdot ecc^2 \cdot \cos(2a)$
$+0.00010615464778 \cdot ecc^3 \cdot \cos(a)$
$-0.0008798679598 \cdot age^2$
$+0.00000280773426 \cdot ecc^4$
$-0.0000012875831 \cdot ecc^4 \cdot \cos(a)$
$-0.0014129981433 \cdot age \cdot ecc$
$-0.0003401844733 \cdot ecc \cdot \sin(a) \cdot age$
$0.00032166521047 \cdot ecc \cdot \cos(a) \cdot age$
$0.01597631687405 \cdot ecc \cdot \sin(a) \cdot \cos(2a)$

FIGURE 10. The formula for predicting the hill of vision for the Octopus 900 *conventional strategy.*

Differential Luminance Sensitivity (DLS) =
31.0625461240191

$$+0.07096445545725 \cdot age$$
$$-0.3067384531149 \cdot ecc$$
$$+0.01099110607538 \cdot ecc^2$$
$$-0.0002827675022 \cdot ecc^3$$
$$-0.0074509870894 \cdot ecc \cdot \sin(a)$$
$$-0.0572536337078 \cdot ecc \cdot \cos(a)$$
$$-0.0077142480717 \cdot ecc \cdot \sin(2a)$$
$$+0.02656731331857 \cdot ecc \cdot \cos(2a)$$
$$-0.0004108840498 \cdot ecc^2 \cdot \sin(a)$$
$$+0.00027033113002 \cdot ecc^2 \cdot \cos(2a)$$
$$+0.00011442748261 \cdot ecc^3 \cdot \cos(a)$$
$$-0.0010759757883 \cdot age^2$$
$$+0.0000021512225 \cdot ecc^4$$
$$-0.0000014389945 \cdot ecc^4 \cdot \cos(a)$$
$$-0.0014341097399 \cdot age \cdot ecc$$
$$-0.000495465098 \cdot ecc \cdot \sin(a) \cdot age$$
$$+0.00039333866591 \cdot ecc \cdot \cos(a) \cdot age$$
$$+0.02107368871175 \cdot ecc \cdot \sin(a) \cdot \cos(2a)$$

FIGURE 11. The formula for predicting the hill of vision for the Octopus 900 *dynamic strategy*.

Differential Luminance Sensitivity (DLS) =
31.3824618404265

+0.07381627920386 · *age*
-0.2884095144585 · *ecc*
+0.009818507665 · ecc^2
-0.0002339663653 · ecc^3
-0.00989070618779 · *ecc* · sin(*a*)
-0.0316031556716 · *ecc* · cos(*a*)
-0.009094821079 · *ecc* · sin(2*a*)
+0.02256010512708 · *ecc* · cos(2*a*)
-0.0008772942746 · ecc^2 · sin(*a*)
+0.00025457385903 · ecc^2 · cos(2*a*)
+0.00007634862054 · ecc^3 · cos(a)
-0.0010464560601 · age^2
+0.00000142630739 · ecc^4
-7.2651894838e-7 · ecc^4 · cos(*a*)
-0.0012078810687 · *age* · *ecc*
-0.0002674782653 · *ecc* · sin(*a*) · *age*
+0.00018780963742 · *ecc* · cos(*a*) · *age*
+0.02748357713276 · *ecc* · sin(*a*) · cos(2*a*)

FIGURE 12. The formula for predicting the hill of vision for the Octopus 900 *GATE-i strategy*.

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