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# Study of Optimal Perimetric Testing In Children (OPTIC)

## Normative Visual Field Values in Children

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***Purpose:*** We sought to define normative visual field (VF) values for children using common clinical test protocols for kinetic and static perimetry.

***Design:*** Prospective, observational study.

***Subjects:*** We recruited 154 children aged 5 to 15 years without any ophthalmic condition that would affect the VF (controls) from pediatric clinics at Moorfields Eye Hospital.

***Methods:*** Children performed perimetric assessments in a randomized order using Goldmann and Octopus kinetic perimetry, and Humphrey static perimetry (Swedish Interactive Thresholding Algorithm [SITA] 24-2 FAST), in a single sitting, using standardized clinical protocols, with assessment by a single examiner. Unreliable results (assessed qualitatively) were excluded from the normative data analysis. Linear, piecewise, and quantile mixed-effects regression models were used. We developed a method to display age-specific normative isopters graphically on a VF plot to aid interpretation.

***Main Outcome Measures:*** Summary measures and graphical plots describing normative VF data for 3 common perimetric tests.

***Results:*** Visual field area increased with age on testing with Goldmann isopters III4e, I4e, and I2e (linear regression; $P < 0.001$) and for Octopus isopters III4e and I4e (linear regression; $P < 0.005$). Visual field development occurs predominately in the inferotemporal field. Humphrey mean deviation (MD) showed an increase of 0.3 decibels (dB; 95% CI, 0.21−0.40) MD per year up to 12 years of age, when adult MD values were reached and thereafter maintained.

***Conclusions:*** Visual field size and sensitivity increase with age in patterns that are specific to the perimetric approach used. These developmental changes should be accounted for when interpreting perimetric test results in children, particularly when monitoring change over time. *Ophthalmology 2015;122:1711-1717 © 2015 by the American Academy of Ophthalmology. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).*

*Supplemental material is available at www.aaojournal.org.*

Perimetry is an important tool in the diagnosis and management of ophthalmic disease. Interpretation of findings relies on an understanding of the normal visual field (VF; i.e., reference values), its natural development and progression throughout the life-course,[1] and the variability of responses in normal subjects.[2] However, there is limited literature in all these areas with respect to children.

Newly developed algorithms for static perimeters undergo extensive testing and normative data are collected, against which test subjects are compared. However, such studies are based on adult subjects, so only adult reference data are available.[2] The effects of testing children and mapping their data to an adult reference are poorly understood, and findings differ according to the test algorithm and examination technique used.[3,4] Thus, there is little guidance available on interpretation of VF data in children, particularly for common static test strategies.

Although the extent of the VF has been reported for Goldmann perimetry in children (currently the "clinical−standard" kinetic measure), the use of large stimuli (V4e and III4e) and sparse test locations limit the clinical application of these existing data.[5,6] The Goldmann perimeter is no longer available commercially, and only 1 study[7] has produced normative isopter area values in children using a kinetic perimeter with similar specifications, namely, the Octopus 900 (n = 82; aged 5−15 years). Furthermore, the development of normative isopter models should account for the nonparametric distribution of points, yet current normative values (in adults and children) have failed to do this.[1,3,4]



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Previous studies have been inconsistent regarding maturation of VFs,[8−13] reflecting the diversity of assessment strategies, procedures, and small sample sizes. The most common tests performed in children in the UK are Goldmann and Humphrey (Swedish Interactive Thresholding Algorithm [SITA]) perimetry.[14] There is some evidence to suggest children without ocular pathology do not reach adult-level sensitivities with the SITA strategy, but reference values are not known.[6]

We report a systematic investigation of fields using Goldmann and Octopus kinetic, and Humphrey static perimetry (SITA 24-2 FAST), in children aged 5 to 15 years, attained using test protocols suitable for a clinical setting.

## Methods

Participants were recruited consecutively from patients known to have disorders that do not impact on VFs attending Moorfields Eye Hospital, London, and their siblings. Where disorders were unilateral, the fellow (unaffected) eye was assessed. Informed, written consent was obtained from parents/legal guardians, and child participants gave verbal assent. To assess eligibility, information on diagnosis, visual acuity, and refractive status was obtained from clinical case notes or for those without medical records (siblings) a full Orthoptic examination, including focimetry where appropriate, was carried out. Table 1 shows the inclusion and exclusion criteria.

Perimetry was performed using a Goldmann perimeter (Haag-Streit, Bern, Switzerland), an Octopus 900 (Haag-Streit), and a Humphrey Visual Field Analyzer 750i (Carl Zeiss Meditec V, Jena, Germany). All tests were carried out in a randomized order (assigned by a pseudorandom number generator; Microsoft Excel 2010, Microsoft, Inc, Redmond, WA), by an experienced orthoptist (D.E.P.) in a dedicated perimetry room, using regularly calibrated perimeters. Children with unilateral amblyopia had their nonamblyopic eye tested and for those with bilateral good acuity and no strabismus/treated amblyopia, 1 eye was tested randomly.

Before testing, participants were made comfortable, familiarized with each perimeter, and given an explanation of the procedure using age-appropriate language. Testing was undertaken in clinical conditions, with a short rest period between tests (approximately 2−3 minutes). Test quality, judged by the examiner using the Examiner Based Assessment of Reliability scoring system, was scored as good, fair, or poor. This system accounts for factors affecting test quality, such as fixation, concentration, behavior, response to auditory stimuli, and fatigue. Data were collected to aid reporting of feasibility and reliability of testing (details reported elsewhere). Significant refractive errors (REs) were corrected using large aperture lenses for the I2e stimulus and static perimetry only using criterion modified from Henson[15]: $\geq$+3.00 diopter spheres, $\geq$−1.00 diopter spheres, $>\pm$1.00 diopter cylinders.

### Kinetic Visual Field Assessments

The familiarization task comprised 3 presentations of the first test isopter. Practice points were not used to form the test isopter. For the test, targets were presented along 12 cardinal meridian (every 30° in a predefined order), centripetally from a nonseeing area using the testing protocol adapted from Werner.[16] Test points were started at manually plotted locations on the Octopus, with an automated speed of 5°/s.[7]

For those children who could tolerate further testing, additional points were tested, in a nonrandomized order along meridians 15° adjacent to the cardinal points starting with temporal field locations. This "filling in" between test points allowed for more accurate plotting of VF shape, up to a maximum of 24 points per isopter. Two isopters were plotted, randomly selected from III4e, I4e, or I2e. The test procedure started with plotting an outer isopter, followed by inner isopter and then finally the plotting of the blind spot, with the I2e stimulus (at a speed of 2°/s).

Test points were replotted if the examiner felt the initial response was unreliable, that is, the child lost fixation during the stimulus presentation, searched for stimuli, failed to respond, or pressed for the noise of stimulus presentation. This accommodated temporary lapses in cooperation, but ensured repeat testing was not undertaken in those with persistently poor cooperation.

### Humphrey Static Perimetry Assessment

Participants were assessed with the SITA 24-2 FAST algorithm with gaze tracking and blind spot monitoring using the Heijl-Krakau method. Participants were warned the lights could be "really bright or quite hard to see" during this test and were told when they reached the midpoint of the test.

### Statistical Methods

Manual perimetry results were scanned and digitized using Engauge digitizer software (open-source; available at: www.digitizer.sourceforge.net) with raw data point values stored in .csv files (Microsoft Excel 2010). Linear and piecewise models were fitted in Stata (StataCorp; 2011: Stata Statistical Software: Release 12. College Station, TX).

The association between mean deviation (MD) and age was modeled as a piecewise linear relationship, where initially a nonlinear least-squares estimation for frequency of MD with age was used to identify the optimum split point of age. Linear associations of age with MD were then fitted and reported separately, before and after the split point.

Raw kinetic perimetry data were exported from the Octopus perimeter and data points extracted using the R package kineticF[17] (The R Project for Statistical Computing, R v3.1.2; available at: www.r-project.org) designed for this purpose. Normative kinetic data were modeled using the linear quantile mixed-effects

Table 1. Inclusion and Exclusion Criteria for Participants

| |
|---|
| Inclusion criteria |
| Children aged 5−15 years. |
| No history of ophthalmologic disease that could cause a visual field defect, but including children with refractive error, unilateral amblyopia and strabismus, where the fellow (nonamblyopic) eye was to be tested. No prior experience of perimetry. |
| Visual acuity of $\geq$0.2 logarithm of the minimum angle of resolution (6/9.5 Snellen equivalent) in the tested eye. |
| Exclusion Criteria |
| Children with any impairments, such as severe learning disability, which would make cooperation with formal perimetry challenging. |
| Children not accompanied by a parent or legal guardian. |

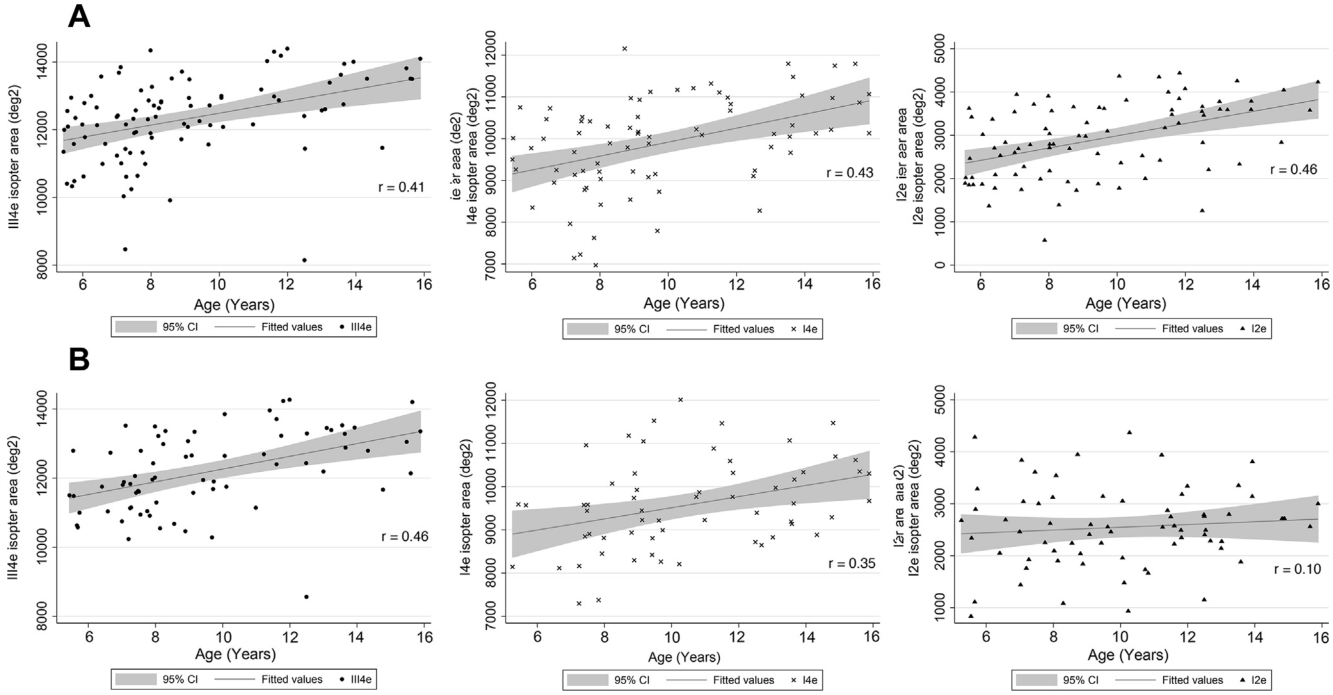


**Figure 1.** **A**, Goldmann visual field (VF) area versus age for isopters III4e, I4e, and I2e. **B**, Octopus VF area versus age for isopters III4e, I4e, and I2e. CI = confidence interval.

regression package lqmm[18] in R (version 3.0.1). This method allows fitting of distribution-free models to individual-clustered data that significantly departs from normality, and was used in the normative model in kineticF to summarize isopter distributions.[17,19] The model developed is described in detail in Appendix 1 (available at www.aaojournal.org).

Raw data were extracted from the Humphrey perimeter using R code developed at City University (Richard Russell, personal communication, January 2013). All left eye data were mirrored along the *y*-axis to represent right eye data for analysis.

The study was approved by the National Health Service Research Ethics Committee for London − Bloomsbury and followed the tenets of the Declaration of Helsinki.

## Results

Between May 2012 and November 2013, 154 participants were recruited from 348 eligible subjects (44.3%). Of the 194 potentially eligible subjects who did not participate, 132 (68%) did not respond to the initial invitation, 34 (17.5%) declined, and 28 (14.4%) agreed but subsequently failed to attend for their assessment. Among the 34 eligible patients who declined to participate, 23 cited time constraints and 11 a lack of interest in contributing to research as the most common reasons. Participants and nonparticipants were of similar age and ethnicity distribution. The median age of participants was 8.0 years (interquartile range, 7.0−11.0) with 81 (52.6%) females (Appendix 2; available at www.aaojournal.org). Of the 154 in the sample, 118 (76.6%) were white, 9.7% Indian, 8.4% black, and 5.2% of mixed ethnicity.

Median RE was 0.0 diopters (D; spherical equivalent; interquartile range, 0−2.5 D; range, −10.00 to +6.75 D). Four subjects (2.6%) had an RE of >−5 D, 9 (5.9%) had >+5 D, and 141 (91.6%) had an RE between ±5 D. Of the 154 participants, 56 (36.4%) had strabismus, and 35 (22.7%) had unilateral amblyopia. Only 1 child (aged 5 years) was tested in a previously amblyopic eye but, owing to poor test quality, these data were not used to generate normative data (for full details, see Appendices 3 and 4, available at www.aaojournal.org). Only data from tests rated as "good" quality (by examiner rating) for reliability were included in the analysis of normative data, that is, those tests performed to a level that would give results representative of true VF sensitivity (Goldmann, n = 125 [81.2%]; Octopus, n = 100 [64.9%]; Humphrey, n = 98 [63.6%]), rather than cases where lack of cooperation affected results.

### Kinetic Perimetry

Visual field area and age were fitted to linear regression models for both perimeters and each isopter (Fig 1). Model coefficients of 176.7 (III4e; 95% CI, 93.8−259.5), 167.3 (I4e; 95% CI, 86.4−248.2), and 141.7 (I2e; 95% CI, 80.9−202.5) were found for Goldmann isopters. These represent the change in area (square degrees) for each additional year of age from 5 to 15

Table 2. Octopus Perimetry Isopter Areas

| | Mean (SD) Isopter area (deg$^2$) | | |
|---|---|---|---|
| **Age Group (y)** | *III4e* | *I4e* | *I2e* |
| 5−6 | 11 426 (806) | 8854 (837) | 2463 (996) |
| 7−8 | 11 867 (977) | 9213 (1084) | 2518 (856) |
| 9−11 | 12 627 (1140) | 9843 (1149) | 2560 (764) |
| 12−15 | 12 731 (1283) | 9807 (832) | 2605 (596) |

SD = standard deviation.
Values shown here are not for reaction time corrected isopters and were formed from straight, not curved (spline), lines.

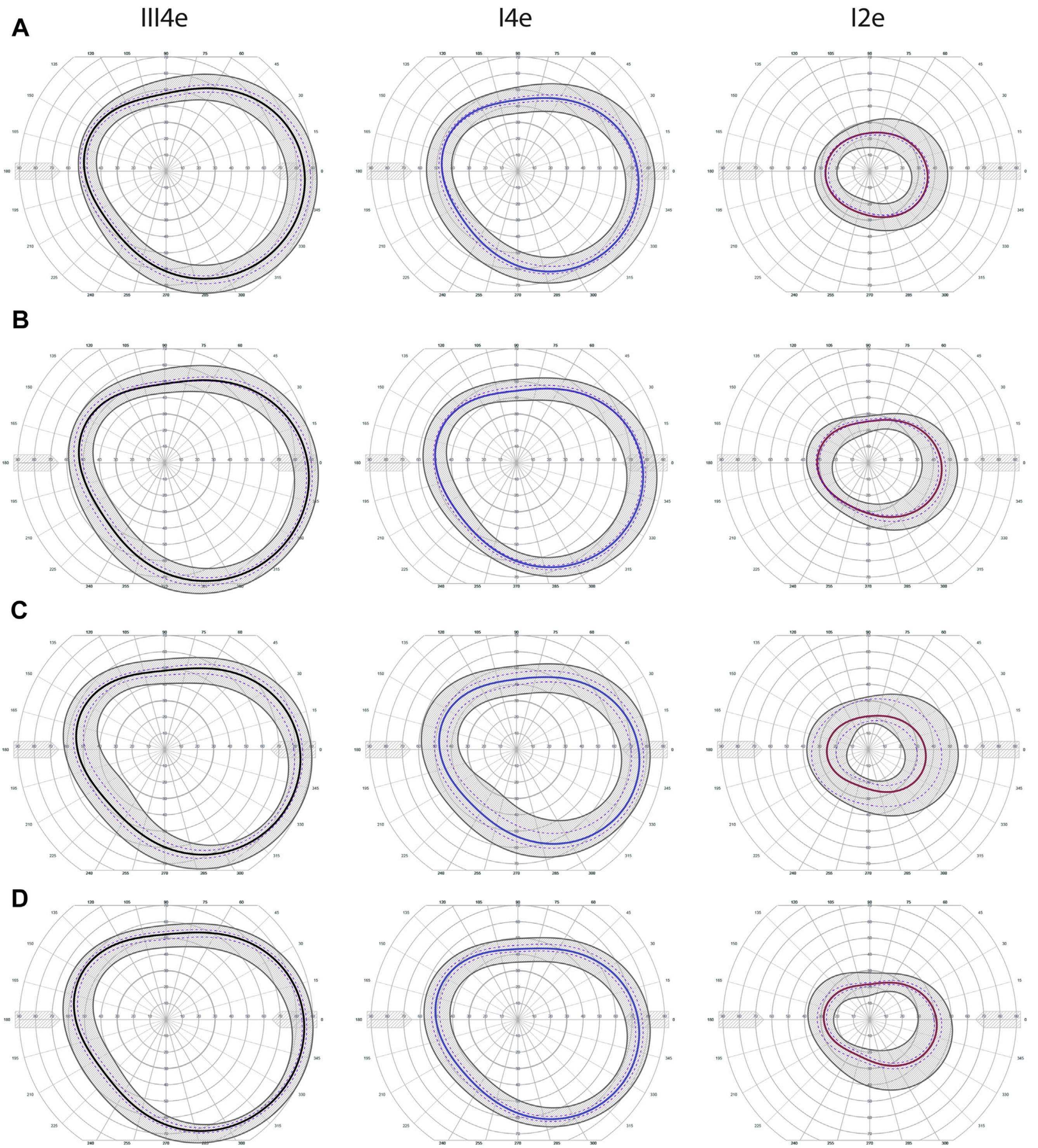


**Figure 2.** Normative data for kinetic perimetry by age group. **A**, Goldmann isopters representing right eye data for subjects aged 5 to 6 years. **B**, Goldmann isopters representing right eye data for subjects aged 13 to 15 years. **C**, Octopus isopters representing right eye data for subjects aged 7 to 8 years. **D**, Octopus isopters representing right eye data for subjects aged 13 to 15 years. *The central, thick band shows median values, with the dashed (purple) lines encompassing the central 50% of data (interquartile range). The grey, hashed region delineates the area containing 95% of the data. Because fewer young children were able to complete Octopus perimetry to a "good quality" rating, the "lqmm" regression model was not sufficiently robust to use in the youngest group. Thus, children aged 7 to 8 years are shown in **C**.

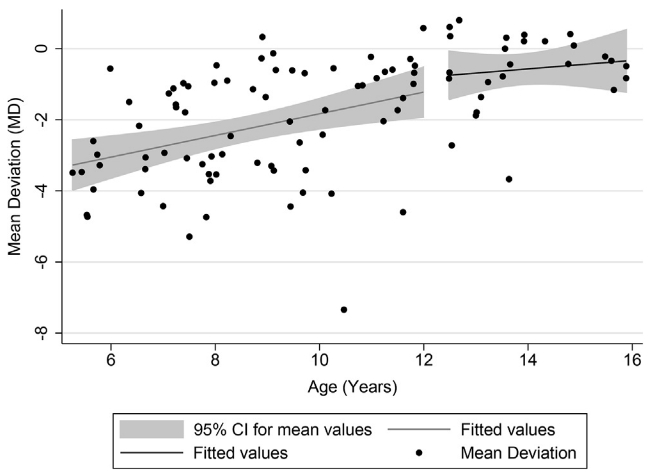


**Figure 3.** Piecewise linear regression of Humphrey mean deviation (MD) scores with age. CI = confidence interval.

years. For Octopus isopters coefficients of 184.4 (III4e; 95% CI, 98.9−269.8), 129.1 (I4e; 95% CI, 39.6−218.5), and 26.7 (I2e; 95% CI, −40.9 to 94.4) were found. With each perimeter, there was a significant increase in VF area with age with all isopters, except the Octopus I2e. Table 2 lists mean isopter area, by age group for the 3 isopters tested using Octopus perimetry. These values are generated by the Octopus during isopter formation and provide clinically comparable data.

Further analysis was undertaken to generate age-group appropriate normative values, presented on a VF plot, thus enabling clinical interpretation. Figure 2A−D shows these data for isopters III4e (black), I4e (blue) and I2e (red). Figure 2 demonstrates differences in VF area by age for Octopus and Goldmann perimetry, with greatest change in the temporal and inferotemporal field (Appendix 4, available at www.aaojournal.org). Isopter III4e demonstrates a "ceiling effect" when reaching the limit of the Goldmann perimeters' testing area. The inner 2.5% quantile line shifts toward a more eccentric position with age for all isopters on both perimeters, and there is a slight narrowing of the 95% region in older subjects, indicating reduced variability in responses with increasing age.

Mean blind spot area for Goldmann perimetry was $80.6^{\circ 2}$ (SD = 27.7) and $63.5^{\circ 2}$ (SD = 29.2) for Octopus perimetry. No relationship between blind spot size and age was found for either perimeter (Goldmann [$P = 0.75$] or Octopus [$P = 0.07$]).

## Static Perimetry

Analysis of MD (a summary statistic produced by the Humphrey perimeter) gives information regarding central VF sensitivity.

Table 3. Average Mean Deviation (MD) Values by Age Group (Humphrey SITA 24-2 FAST)

| Age (y) | Average MD Value (SD) |
|---|---|
| 5−6 | −3.22 (1.16) |
| 7−8 | −2.15 (1.42) |
| 9−11 | −1.85 (1.75) |
| 12−15 | −0.58 (1.05) |

SD = standard deviation.

Regression models revealed an association between age and MD, and further analysis (by piecewise regression; Fig 3) establishes a point of change in this relationship at 12 years of age. Between the ages of 5 and 12 years, the estimated slope is 0.30 (i.e., a 0.3-dB increase in sensitivity per unit increase in age; 95% CI, 0.21−0.40). After 12 years of age, there is no association ($P = 0.526$) and MD values are similar to adult levels (i.e., average MD ≈ 0; Table 3).

## Discussion

We report the first normative data for children using common VF tests, using protocols suitable for use in clinical practice. They provide baseline values against which clinical VF tests can be assessed (templates available on request from the authors). Our findings show that the size/area and sensitivity of normal VFs increases with age. We also report new analytical methods for the analysis of kinetic fields (Appendix 1, available at www.aaojournal.org).

Our findings show that with Goldmann perimetry, the mean isopter area for isopter III4e was 17.8% larger, isopter I4e was 11.2% larger, and isopter I2e was 63.1% larger in 15-year-olds compared with 5-year-olds, a large change in VF areas over this 10-year range. This translates into a visible change in isopter appearance between the youngest and oldest subjects (Fig 2A, B), but with overlapping confidence estimates between age groups. It is critical to note that the inner 2.5% quantile line increases in size with age. Thus, previously "normal" values in young children are no longer "normal" as age advances. Most of the developmental change occurs in the temporal and inferotemporal field, with a small increase in nasal field size (Appendix 5, available at www.aaojournal.org).

Direct comparisons of VF area between Goldmann and Octopus perimeters are not appropriate, because the Octopus perimeter has a slightly smaller test area (affecting only far peripheral stimuli) and does not have a "void" area at 90° and 180°.

Humphrey MD values are a commonly used metric in the summary of VF data in children. This study reports normative SITA FAST values in children. Our findings show MD values to be age dependent and their interpretation should therefore account for subject age. Children <10 years of age should not be expected to attain adult VF sensitivity levels (Table 3). Between 10 and 12 years, there is a good likelihood of achieving adultlike results (MD > −2 dB) and children >12 years should be expected to achieve adult sensitivity levels routinely. Likewise, frequency doubling (static) perimetry (FDT) uses an underlying adult normative database, against which test results are compared and children do not reach adult levels of sensitivity with FDT until 14 years of age.[9]

Finally, perimeter-specific assessment factors should be considered when interpreting findings, that is, the ease of positioning child subjects, the effect of audible stimulus presentation, and fatigue effects.

To our knowledge, our study is the largest of its kind to date in children, and assessed multiple common perimetric tests, using clinically suitable protocols and robust analyses. Potential sources of bias, such as learning and fatigue, were minimized by randomizing test order. We included children without binocular functions/stereopsis to ensure that the sample reflected the target population for VF testing in a clinical setting and evidence has shown that "fellow" eyes in children with strabismus have normal VFs.[11,12]

The study was designed with an awareness of the issues surrounding data capture of subjective responses in children. Our pragmatic approach allowed us to generate normative data for 3 perimetric assessments, but meant we were unable to measure both eyes or assess repeatability in a single sitting. Other limitations include the reduction of sample size after the exclusion of tests that were not rated as having "good" reliability (approximately one-third of the total sample for Octopus and Humphrey perimetry), precluding analysis of Octopus perimetry using the quantile regression model in the 5- to 6-year age group.

It is difficult to compare directly our kinetic data with the extant literature reporting VF size in children, because prior research involved assessments along fewer meridians, using large stimuli (V4e) only,[5,6] or had a small sample and analyzed with parametric methods.[20] However, visual inspection does show that our results in the oldest children are similar to the results of Egge[1] in 14- to 15-year-olds ($n = 68$, Goldmann perimetry), albeit with a slightly smaller nasal field in our study, but similar confidence estimates.

For Octopus perimetry, normative isopters have been modeled previously in adults using parametric methods and are therefore not comparable with the data presented here. We have produced area data for Octopus perimetry, and elected not to correct for reaction time as children can demonstrate variable reaction times through the course of a single test, and thus our results are not comparable with others.[7] Spline models describe changes of isopter values in relation to isopter area by fitting a nonparametric smooth function using curved lines. The use of linear models in our study, using straight as opposed to curved lines when estimating isopter area, affects the generalizability of these results.

Our findings provide normative, age-dependent VF values in children, to serve as the basis for interpretation of VF test results in children with ophthalmic disease. They provide a means of bridging the gap in normative data for Goldmann,[1,3] Octopus,[4] and Humphrey[2] perimetry. We provide evidence for linear VF growth during childhood (between 5 and 15 years) as measured with kinetic perimetry (both Goldmann and Octopus), whereas static perimetry (Humphrey SITA) results reach adult levels at 12 years of age. We suggest that interpretation of perimetric findings should be based on knowledge of the normal range of area/size or sensitivity reported here. For example, when monitoring progressive VF loss longitudinally in young children, a failure to demonstrate larger/more sensitive VFs over a number of years may indicate loss of VF function or arrested development, rather than stability. Further planned work in this program of research will assess the utility of perimetry in children with glaucoma and neuro-ophthalmic disease, developing the understanding of the role of perimetry in diagnosing and monitoring ophthalmic disease in children.

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Abbreviations and Acronyms:
****D** = diopter; **MD** = mean deviation; **RE** = refractive error; **SITA** = Swedish Interactive Thresholding Algorithm; **VF** = visual field.

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