The Reliability of Frequency-Doubling Perimetry in Young Children

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Objective: To evaluate whether healthy young children are able to perform automated static perimetry reliably using the frequency-doubling technology (FDT) perimeter.

Design: Prospective, observational case series.

Participants: Forty healthy children aged 4 to 14 years.

Testing: Subjects underwent, in 1 randomly chosen eye, 2 consecutive visual field (VF) tests using the C-20 full-threshold program of the commercially available FDT.

Main Outcome Measures: Global measures included mean deviation (MD), pattern standard deviation (PSD), test duration and reliability indices, including fixation losses and false-positive and false-negative errors. Fixation losses are checked 6 times throughout the examination, rather than being continuously monitored. Two scoring systems, based on the total deviation probability plot, classified each VF as normal or abnormal.

Results: All subjects completed the VF test. The better of 2 examinations (as determined by the MD score) was used for analysis. The average test duration was 4.9 ± 0.7 minutes for the entire group. The mean MD and PSD were -0.78 ± 4.9 and 6.7 ± 6.2, respectively. A clear correlation to age was found for MD, PSD, abnormality of the VF, and test duration (all $P<0.05$). Of all VFs, 32.5% were unreliable, such that at younger than 8 years of age, 42.9% of the VFs were unreliable, compared with 23.1% for those older than 8 years. Younger than 8 years of age, 78.6% of VFs were abnormal, whereas for ages 8 years and older, 26.9% of VFs were abnormal.

Conclusions: Frequency-doubling technology seems to be a clinically feasible VF method for evaluating young children older than approximately 8 years of age. The reliability indices, MD, test duration, and the reproducibility of the VF test were found to be highly correlated with age, in such a way that these parameters all improved with increasing age. *Ophthalmology 2004;111:435–439 © 2004 by the American Academy of Ophthalmology.*

Visual field (VF) testing is an important component of evaluating the visual system, especially for diagnosing ocular disorders that affect the field of vision, such as glaucoma and certain retinal and neurologic disorders.[1] However, the subjective nature of the testing and the need to maintain steady fixation for a considerable length of time seems to limit its usefulness in the younger age group.[2]

Frequency-doubling technology (FDT) perimetry (Welch Allyn, Skaneateles, NY; Zeiss-Humphrey, Dublin, CA) is a relatively new perimetric approach that makes use of the frequency-doubling illusion, initially described by Kelly,[3,4] to stimulate a subpopulation of the large retinal cells known as the Magnocellular cells.[5] These Magnocellular cells are believed to be preferentially stimulated by low-spatial high-temporal frequency.[5,6]

By stimulating a subset of large ganglion cells, cells that may be damaged early on in glaucoma,[7,8] VF testing based

on the FDT stimulus may offer earlier detection of ganglion cell dropout in glaucoma.[9] Regardless of the population of ganglion cells stimulated, FDT perimetry offers several advantages over standard automated perimetry, such as: significantly shorter test duration[10]; a larger (and perhaps a more consistently notable) stimuli target; tolerance to relatively large refractive errors[11]; a more convenient office setup (a smaller, less expensive unit, as compared with standard automated perimetry, and the ability to test with room lights on) and having both eyes open during the test, as opposed to the need to patch one eye at a time during standard automated perimetry testing. In children, FDT perimetry offers, in addition, 2 potential advantages: the fact that the target appears to move, which may hold the children's attention, and the fact that there is no bowl, so children are less likely to feel claustrophobic.

Visual field data are largely lacking for the pediatric population. An age-adjusted normative database does not exist, and the age cutoff, over which reliable data gathering is deemed possible, is largely unknown. Owing to the above-mentioned advantages of FDT perimetry, which seem more significant when dealing with a restless, inattentive young child whose capacity to perform a lengthy difficult task is limited, we set out to evaluate the feasibility of FDT perimetry in normal young children.

Uncertainty exists regarding a young child's capacity for

undertaking a visual field examination and, more so, a monotonous, lengthy examination. When testing a child, difficulties in learning the task,[12,13] in maintaining stable fixation on the central target,[14,15] and in sustained concentration, as well as resultant fatigue,[16] may lead to frequent fixation losses, low reliability, or the inability to complete the entire examination.

Safran et al,[2] who evaluated the reliability of automated VF testing in children using the Octopus 2000R perimeter, concluded that a preliminary familiarization phase with a special adaptation program is mandatory for testing children younger than 7 years. This additional training period limits the practicality of integrating this diagnostic method in a busy clinical setting. Morales and Brown[17] evaluated the feasibility of VF testing, using the Octopus 1-2-3 perimeter program TOP-32 in children aged 6 through 12 years, and concluded that in a clinical setting, reasonably accurate results may be anticipated with children older than 7 years.

Materials and Methods

Forty healthy children aged 4 to 14 years were recruited from the general population. All children underwent a complete ophthalmic examination of both eyes before recruitment, including best-corrected visual acuity testing by Allen pictures in the preschool age group and Snellen charts in school-age children, ocular alignment by cover–uncover and alternate-cover test, sensory binocular function by Titmus fly test, slit-lamp examination, and a dilated stereoscopic fundus examination (both slit-lamp biomicroscopy as well as indirect ophthalmoscopy of the peripheral retina) to rule out glaucomatous-appearing optic nerves, evident as rim thinning, notching, or excavation, as well as other disc or retinal pathologic features that may result in VF defects. Lastly, each child underwent a full cycloplegic refraction.

Excluded from the study were children with a prior history of eye surgery or eye trauma, with amblyopia, with past or current strabismus, or with any ocular or systemic disease that might have affected the VF. All children were recruited from mainstream schooling. The child's parents or the accompanying adult were questioned to rule out gross behavioral problems. Children known to have attention deficit disorder and children receiving amphetamines, stimulants, or sedatives also were excluded from this study.

Inclusion criteria were: age 4 through 14 years, best-corrected visual acuity of at least 20/30 in each eye, a spherical equivalent refractive error of between +3 and −3 diopters (D), a cylindrical component not more than 3.5 D, and stereopsis of at least 60°. Informed consent was obtained from the child's parent or legal guardian before commencement of the examination, and the Hospital Human Subject Committee approved the methodology.

All children underwent 2 consecutive VF tests, spaced 5.9±7.7 minutes apart in 1 randomly chosen eye, using the commercially available FDT device. Before testing, a verbal explanation of the task was provided to the child, as well as a quick practice trial (less than 1 minute in duration) to ensure that the child understood what was expected of him or her.

The C-20 full-threshold program (FDT/VF software version 2.60/1.00) was used for all examinations. The entire grid pattern encompasses 20° from fixation in each direction and is made of 16 square test locations, each spanning 10° across, and, in addition, a central (foveal) 10° circular grid location. The FDT target is a black-and-white sinusoidal grating (0.25 cycles/degree) flickering at 25 Hz, randomly presented in each of the test locations. The contrast between the dark and white bars is varied throughout the test according to the subject's response. Threshold values are then determined at each location from the log contrast sensitivity and are expressed in decibels.

All children were tested by a single trained operator (AHa) using one FDT machine stationed in a designated room with constant standard room lighting from 2 fluorescent lamps of 40 watts each. Subjects were given the option of perform the test with either their habitual glasses or without them, because myopia up to −12 D was shown not to affect FDT results.[11] An opportunity was given to interrupt the test for repositioning or if the child felt uncomfortable or wished to rest during the test. A break was encouraged between the first and second test, and the child indicated when he or she wished to perform the second test.

Global parameters provided on the FDT printout used in the analysis included test duration, reliability indices, MD, PSD, and the total deviation plots. However, none of these parameters provides a clear indication as to whether any particular test is normal or abnormal. Reliability parameters (fixation errors, false-positive errors, and false-negative errors) were deemed unreliable when >33% were flagged on the FDT printouts. A global, all-inclusive, parameter reliably flagging abnormal test does not exist on the FDT printout, as opposed, for instance, to the glaucoma hemifield test analysis present on the Humphrey Field Analyzer (Humphrey-Zeiss, Dublin, CA) printout.[18] Several scoring systems were used previously to evaluate normality of FDT VFs. Khong et al[19] counted the total number of locations flagged at the 1% probability level or worse, then classifying that eye in relation to the likelihood of finding VF abnormalities on the HFA. He concluded that as many as 5 or more abnormal FDT locations were needed to define a definite VF defect. Sample at al[20] considered an FDT field with a cluster of 2 adjacent misses at 5% or worse probability limits to be abnormal; however, this scoring system seems to be tuned specifically for picking up the retinal nerve fiber bundle defect pattern characteristic of glaucoma. Realizing that the VF defects in normal, yet young, children may be scattered in a random pattern, seeking a simple scoring system and realizing that a strict cutoff for normality is not desired when testing a pediatric population, we chose initially to count the total number of test locations (not including the foveal location) showing, on the total deviation plot, a 1% or worse probability cutoff level, and set out to analyze what may constitute a reasonable cutoff for normality.
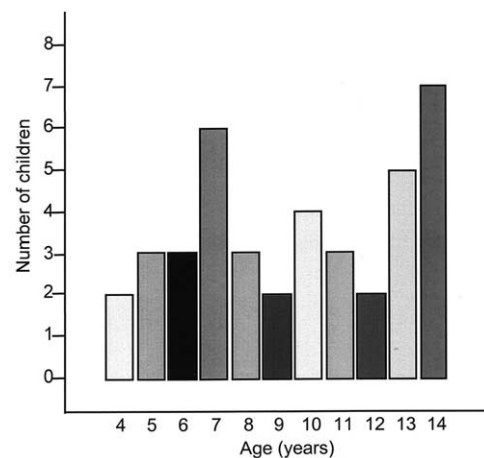

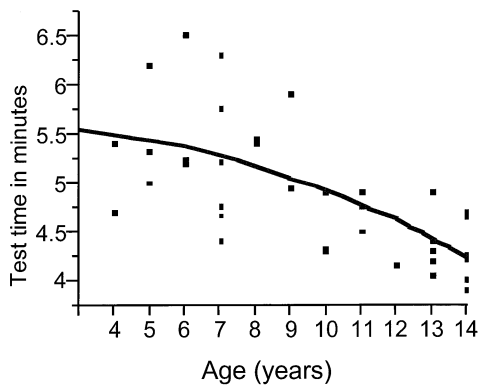**Figure 1.** The distribution of subjects by age.

Figure 2. Average test time in minutes by age. A significant decrease of test time was found with increasing age ($P<0.005$).
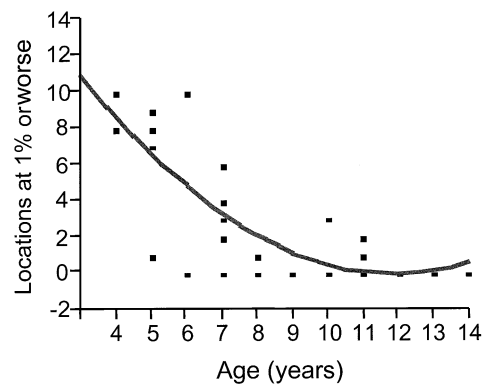

Figure 4. Number of abnormal locations at 1% probability or worse, by age.

A second scoring system developed for this study is based on identifying those locations that have shown a consistent abnormality evident on both VFs. For each of the 16 locations (not including the foveal location), the better of the 2 probability values in the total deviation plot was noted. We then counted the number of abnormal locations at the 1% or worse probability cutoff level, and again at the 2% or worse probability cutoff level. This scoring system identifies reproducible focal abnormalities.

Data were exported from the FDT device into Excel (Microsoft, Redmond, WA) and analyzed using JMP statistical software (SAS Institute, Cary, NC). A paired *t* test and analysis of variance (ANOVA) were used for statistical analyses.

Results

Forty children aged 4 to 14 years (mean age, 9.0 ± 3.3 years; Fig 1) underwent 2 consecutive C-20 program full-threshold VF tests using the commercially available FDT perimeter. One randomly chosen eye of each child was tested twice. Twenty-four of the children were males, and 16 were females. Test duration for the first and second examinations was 4.9 ± 0.7 minutes and 5.0 ± 0.8 minutes, respectively. The entire testing session, including an introduction, 2 VF tests, and the intertest rest period, spanned 14.0 ± 2.4 minutes. For all analyses presented, the better of the 2 examinations (as determined by the MD score) was used. A statistically significant shortening in test duration was found with

increasing age (Fig 2) when comparing the first, second, and better tests (all $P<0.005$, ANOVA).

Reliability indices (fixation errors, false-positive errors, and false-negative errors) for the better of the 2 tests (based on the MD score) were inversely correlated with increasing age; however, none reached statistical significance ($P = 0.26$, $P = 0.75$, and $P = 0.19$, respectively, ANOVA). Both MD and PSD improved with increasing age in a statistically significant manner ($P = 0.07$ and $P = 0.04$, respectively, ANOVA; Fig 3). At younger than 8 years of age, 42.9% of the VF tests were unreliable, compared with 23.1% from children older than 8 years of age. This reliability further improved with age, in such a way that for children 9 years and older and 10 years and older, 17.4% and 14.3% of the VF tests were unreliable, respectively.

Two different scoring systems were used for evaluating the normality of VF tests. Counting the total number of abnormal locations at the 1% or worse probability cutoff on the total deviation plot showed a significant decrease in the number of abnormal locations with increasing age ($P<0.0001$, ANOVA; Fig 4). A significant correlation with age also was noted when overlaying the 2 total deviation statistical probability plots, 1 on the other, and counting the number of abnormal locations at the 1% or worse and 2% or worse probability cutoffs ($P = 0.002$ and $P = 0.008$, respectively, ANOVA; Fig 5). At younger than 8 years of age, 78.6% of the VFs were abnormal, whereas for 8 years of age and older, 26.9% of VFs were abnormal (Fig 6). An abnormal VF was defined as having 1 or more abnormal locations in any 1 of the 3 scoring systems.
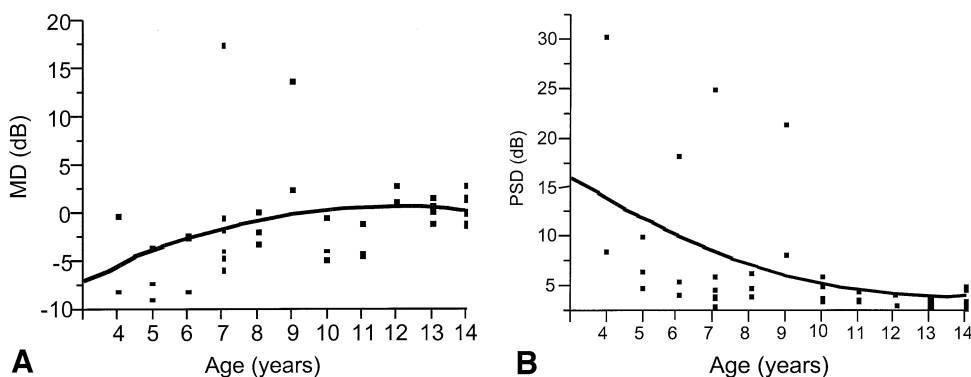

Figure 3. A, Mean deviation (MD) by age. An improvement in MD was noted with increasing age ($P = 0.07$). **B,** Pattern standard deviation (PSD) by age. A decrease in PSD was noted with increasing age ($P = 0.04$).
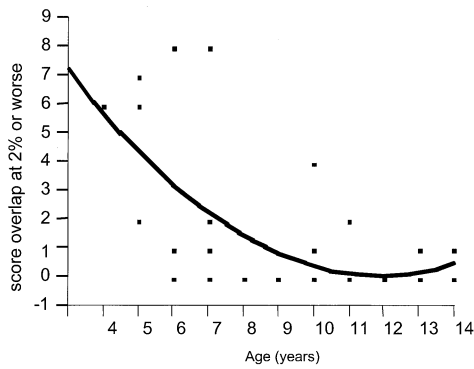
Figure 5. Number of overlap abnormal locations at 2% or worse, by age.

Discussion

Several studies evaluating the FDT in adults have shown this technique to be highly specific and sensitive for the detection of VF abnormalities, comparable with standard automated perimetry.[20-22] Our study evaluates the feasibility of FDT VF testing in young, normal children, seeking a cutoff age after which such testing is deemed feasible and reliable. Visual field testing holds several caveats when testing young children. The normative FDT database used in the device does not extend to include the pediatric population, and hence, any regression analysis-derived age adjustments may not be valid. Second, most existing scoring systems were designed specifically and tested to flag glaucomatous visual field defects, whereas in our study, the abnormality for which the test is designed is primarily task immaturity. Third, and most important, a child's short attention span may render the use of a lengthy monotonous test such as perimetry clinically less meaningful.

The age cutoff over which automated static perimetry can be presumed to be reliable so far has not been well investigated or defined. Although the FDT device holds several advantages when examining young children, we are not aware of any such studies on this device. Morales and Brown[17] set to evaluate the feasibility of the Octopus TOP-32 program on the Octopus 1-2-3 automated perime-

ter. They concluded that automated perimetry is dependent on the individual maturity of the child, with the most reliable results obtained beyond the age of 7 years. Safran et al,[2] evaluating a group of girls aged 5 to 8 years using the Octopus 2000R perimeter, showed a significant improvement of stimulus detection with age ($P<0.0001$). This group also recommended a familiarization phase with a specially designed teaching program for children younger than 7 years.

Our study shows clinically meaningful improvement with age of all threshold-derived parameters, abnormality classification scores, and reliability parameters. Almost all were statistically significant. Surprisingly, the reliability indices showed the least amount of improvement with age, with false-positive errors demonstrating the least significant correlation with age.

Most importantly, we set out to determine an age cutoff after which children are able to produce normal FDT VFs. With each of the 3 scoring systems used to define abnormality in VFs, we found little improvement beyond the age of 8 years, such that beyond this age, little difference was found between the different age groups in our limited sample of children tested. Although a clear and continuous improvement trend was found for most parameters (Figs 2–6), our cumulative data suggest that, somewhere between ages 7 and 8, children are mature enough to be able to perform what appears to be a meaningful FDT VF examination. It should be noted that even children as young as 7 years were able to perform an FDT VF, with nearly half of the children performing a reliable VF. Because age is only one factor that determines child maturity, it is reasonable to expect that this age cutoff will differ among individual children. Also, we speculate that with additional training and multiple preliminary testing (an extended learning effect[23]), this age cutoff may be lowered.

It is important to note that a child's ability to perform a reliable VF does not necessarily imply that the FDT can localize glaucomatous VF defects or VF defects resulting from neurologic disease in this age group. Further study is needed to qualify specifically the ability of the FDT to detect such abnormalities in children. The reader should also note that we used the FDT twice, but only analyzed the test with the better mean deviation. If a subject is only tested once in the clinician's office, it is likely that the proportion of reliable tests may be lower than we report.

On a technical note, during the VF testing, several children were handicapped from poor visibility resulting from fogging of the LCD panel of the FDT device. This especially may affect younger children, who may place their face too close to the screen because the standard facemask in the unit may be too large for them. We recommend noting and correcting for this phenomenon of accumulated vapor from the child's breath on the FDT viewing lens.

In conclusion, we found a clear correlation between age and performance on the FDT device, such that normal children 8 years of age and older were able to produce reliable tests, whereas those 7 and younger seemed not to be mature enough to provide clinically meaningful tests. We hope that future studies can refine further the age cutoff found in our study, develop newer algorithms and protocols
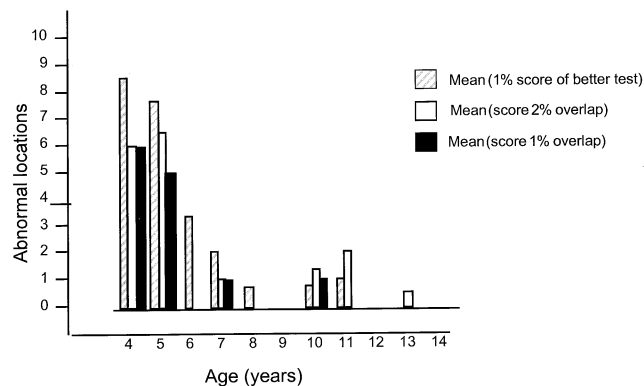

Figure 6. Mean number of abnormal locations found using 3 scoring systems (see "Materials and Methods"). A decrease in the number of abnormal locations with increasing age was found for all systems used.

for testing young children, and extend the normative database to include the pediatric population.

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