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Article

Development of a Pediatric Visual Field Test

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Purpose: We describe a pediatric visual field (VF) test based on a computer game where software and hardware combine to provide an enjoyable test experience.

Methods: The test software consists of a platform-based computer game presented to the central VF. A storyline was created around the game as was a structure surrounding the computer monitor to enhance patients' experience. The patient is asked to help the central character collect magic coins (stimuli). To collect these coins a series of obstacles need to be overcome. The test was presented on a Sony PVM-2541A monitor calibrated from a central midpoint with a Minolta CS-100 photometer placed at 50 cm. Measurements were performed at 15 locations on the screen and the contrast calculated. Retinal sensitivity was determined by modulating stimulus in size. To test the feasibility of the novel approach 20 patients (4–16 years old) with no history of VF defects were recruited.

Results: For the 14 subjects completing the study, 31 ± 15 data points were collected on 1 eye of each patient. Mean background luminance and stimulus contrast were 9.9 ± 0.3 cd/m^2 and 27.9 ± 0.1 dB, respectively. Sensitivity values obtained were similar to an adult population but variability was considerably higher – 8.3 ± 9.0 dB.

Conclusions: Preliminary data show the feasibility of a game-based VF test for pediatric use. Although the test was well accepted by the target population, test variability remained very high.

Translational Relevance: Traditional VF tests are not well tolerated by children. This study describes a child-friendly approach to test visual fields in the targeted population.

Introduction

Visual field (VF) assessment is performed routinely in adults over the age of 40 and much research has been focused on the development of these tests. As in adults, visual function is also a fundamental part of pediatric clinical management in ophthalmic disease. However, development of VF tests for a pediatric population has received less attention, perhaps due to the challenges one faces to reliably assess visual function on this population.[1,2] Previous studies have proposed adult-based tests,[3–6] while others used techniques specifically targeting the pediatric population.[7–14]

Visual fields assessment is a psychophysical process dependent on the functional integrity of the visual system and cognitive factors. Children do not meet all the requirements of the test to the same standard as an adult, nor are they comfortable with the restrictions they traditionally impose. Undoubtedly, the most demanding requirement asked of a child during adult-based perimetry is to maintain fixation on a central target.[9,14–16] This requires a conscious effort to inhibit the natural response to orientate to the presented stimuli.[15,16] Children also have a reduced ability to understand the task required,[4,16] hence, are more likely to provide inappropriate responses as evidenced by the higher rates of false-positive/-negative responses compared to adults.[5,17] Children have a shorter attention span and are less cooperative and more easily distracted

than adults, making typical adult-based tests difficult to perform.[4,16] Of concern, is the use of adult-based normative databases in subsequent measures of test performance. Although it still is debatable whether visual function undergoes development during childhood,[17–24] test variability is likely to be higher in this population.[25–27] Knowledge of test variability is integral to measures of test performance and algorithms.

Our group previously has described a novel concept for pediatric VF testing based on a computer game, where software and hardware combine to provide an enjoyable test experience.[7] Our goal was to improve the usability of the test to further enhance patients' experience, while at the same time improving the psychophysical characteristics of the test (e.g., stimulus size, luminance, duration). We described the test hardware and software procedures and investigated the feasibility of using this test to collect a normative database in the target population.

Methods

Tools and Calibration Procedure

The test software was developed in MatLab-2014A (MathWorks, Inc., Natick, MA) using Psychtoolbox-3.0.11, PTB,[28–30] on an Apple iMac computer (Apple, Inc., Cupertino, CA). The game was displayed on a Sony PVM-2541A (Sony Corp., Tokyo, Japan) organic light-emitting diode (OLED), with 0.28 pixels/mm resolution and 60 Hz refresh rate.

Monitor temperature is known to impact luminance output values of cathode ray tube (CRT) and thin-film transistor (TFT) panels,[31] but its impact is likely to be lower on LED/OLED based systems. Monitor warm-up time was investigated to determine the length of time required for luminance levels to stabilize. Luminance output was measured every 2 minutes for a 1-hour period at 25%, 50%, 75%, and 100% of maximum screen output. For each time point, 5 repeated measurements were performed. Monitor's γ was investigated to produce a linear relationship between RGB coordinate (input) and luminance (output). The monitor was turned on 1 hour before data collection. Luminance was measured for different RGB coordinates ranging from 0 to 255 in 5 RGB steps. Gamma was determined for the different color channels separately and for the gray scale. The equation that best fits the data collected was determined and the inverse of that function calculated. Gamma correction and monitor warm-up time were investigated using a ColorCAL MKII (Cambridge Research Systems Ltd, Kent, United Kingdom) placed perpendicular to the monitor. Measurements were performed on a rectangular patch equivalent to 20% of the screen width. The rectangular patch was presented on the vertical and horizontal midline of the monitor.

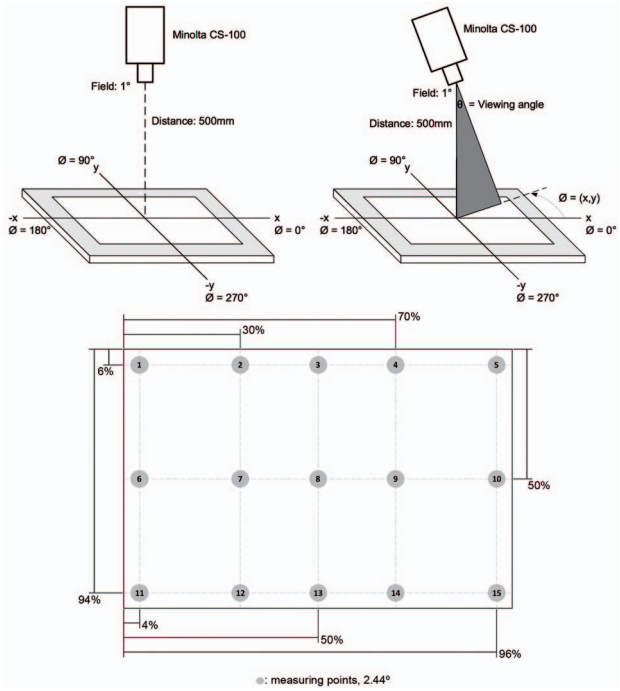

Figure 1. Measurement technique for central, *top left*, and peripheral, *top right*, areas of the screen and calibration locations on the Sony OLED monitor, *bottom*.

Background and stimuli luminance were measured from a central midpoint with a Minolta CS-100 (Konica Minolta, Inc., Tokyo, Japan) spot photometer placed at 50 cm. Measurements were performed at 15 different locations on the screen (Fig. 1) and luminance was interpolated between tested locations.

Background was set at 10 cd/m^2 and contrast was calculated on the basis of the Humphrey Field Analyzer scale (HFA; 3183 cd/m^2 maximum brightness). Due to the narrow dynamic range of contrast, thresholds were determined by modulating stimulus area rather than contrast. Sizes ranged from 0.046° to 2.441° subtended, increasing in area by a factor of 1.19 log units. This scale was based on the area subtended by a stimulus of 1 pixel presented on a central location of the VF, up to 2 stimuli larger than an equivalent Goldmann size V. From the set range, three stimulus areas were removed due to monitor's pixel density limitation (Fig. 2). Stimuli were scaled

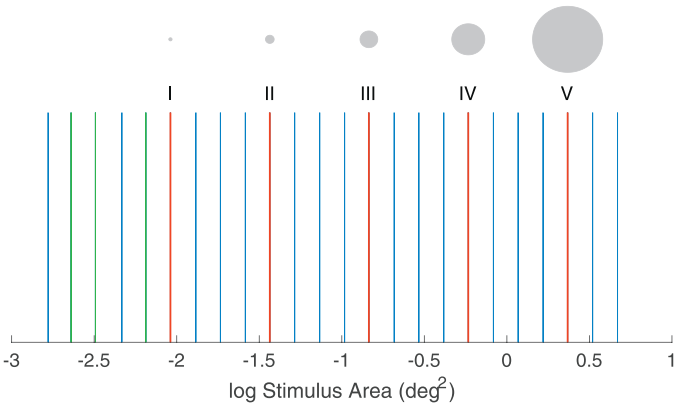

Figure 2. Stimulus areas available to test. Values in *red* represent the 5 Goldmann size stimuli and values in *green* were removed due to pixel density limitations. Both values in *red* and *blue* were available in the test.

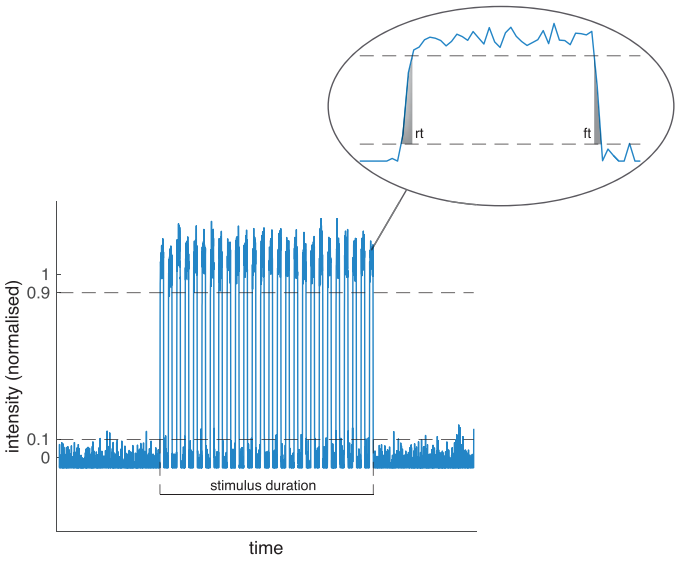

Figure 3. Schematic for stimuli presentation duration. *Blue line* represents the data collected and interpolation between data points for a typical OLED panel; *horizontal gray dashed lines* represents the 10% and 90% bounds of the intended light intensity transition. The *magnified region* represents a single peak. Rise time (RT) is the period it takes for a transition between 10% and 90% intensity on the first frame. Fall time (FT) is the period necessary for a transition between 90% and 10% intensity on the last frame. Rise time and FT were calculated as the mean RT and FT for each peak.

with eccentricity to compensate for viewing angle on a tangent platform. For each eccentricity, error was calculated as the differences between the intended and presented central stimuli sizes.

Stimuli were presented at 15 cd/m^2 for 200 ms or until the "seen" button was pressed (whichever came first). A low contrast stimulus was chosen to increase the relationship between ganglion cell density and VF sensitivity[32–36] within the dynamic scale available.

An Optical Transient Recorder (OTR-3; Display-Metrology & Systems, Karlsruhe, Germany) was used to compare PTB self-reported and the actual stimulus duration. Ten thousand voltage samples were recorded for 1 second by placing the OTR-3 head perpendicular to the monitor and aligned with the center of a patch, comprising 20% of the screen width resolution. This patch was presented on three areas of the monitor, one at a time: top left-hand corner, center, and bottom right-hand corner. These locations were picked to investigate differences in stimuli duration with monitor refresh rate. Measurements were repeated on two different days and on each day twice. Using the RGB coordinates obtained during luminance calibration, the patch was presented alternating between background and stimuli luminance, and also stable at each of the two luminance levels. For the stable presentations, background and stimuli voltage signal were processed using an upper root-mean-square envelope of the values. The mean of the envelopes was used to normalize the data. For the alternating presentations, the transition between intensities was programmed to change every 200 ms. Monitor rise time was taken as the interval of time necessary for a transition between 10% and 90% and fall time the transition between 90% and 10% of the intended luminance level for each peak during stimulus presentation. Total duration of presentation was determined as the period of time between a 10% increase in voltage of the first rise to the same voltage level of the last fall (Fig. 3). Analysis of variance was used to compare results at different regions of the monitor and between PTB self-reported and OTR-3–measured results.

Response window, period of time to wait for a child to press the button, was set at 2.5 seconds and increased or reduced progressively according to collected response times. Response window was updated only after the fifth presentation was performed and the minimum time allowed was set to 1 second. Recovery time after a stimuli response was set to 1 second.

To draw the attention of the child and increase the willingness to play the game, a castle-like structure was built around the computer monitor. On this structure an opening placed 50 cm away and centered on the horizontal and vertical midline of the monitor was created, and a headrest sensor mounted above. If

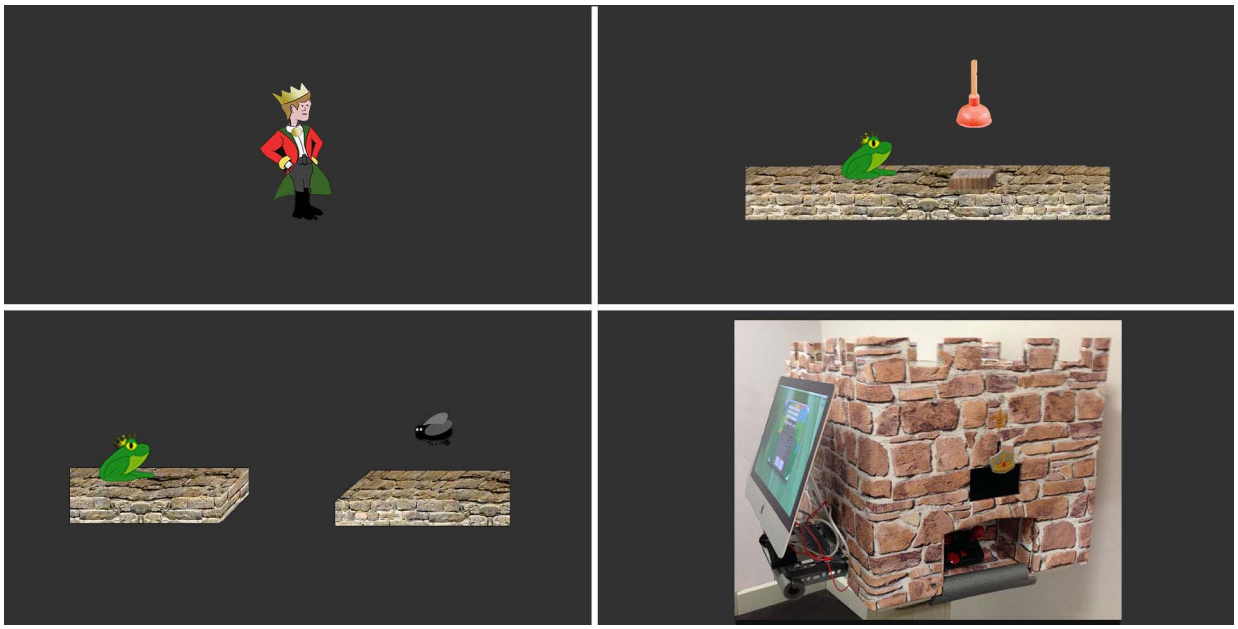

Figure 4. *Top left*: Image of the central character of the game before being cursed by a witch. *Top right* and *bottom left*: Magnification of the images of the central character transformed into a frog and obstacles to overcome. *Bottom right*: Apparatus for the computer game. The OLED monitor is situated inside the castle-like structure.

the patient moved away from the castle, the game paused.

Development of the Computer Game

To stimulate child cooperation and control fixation, we developed a platform-based computer game shown to the central VF, 9.96° horizontal and 2.17° to 6.93° vertical (Fig. 4). A storyline was created around the game, which complemented the castle-like structure surrounding the monitor. The patient was asked to help the central character, a prince cursed by a mean witch that transformed him into a frog, collect magic coins (stimulus). These coins gave him powers to reverse the curse. To progress to the next level in the game a series of obstacles had to be overcome. Each level involved an increase in game speed and occurred according to game-time played. When obstacles appeared on screen, the children had to interact with the game by moving a joystick up or down, "jump" or "shrink," respectively. Response to the obstacle was time-sensitive and required fixation, which was likely to alternate between the obstacle and the central character (frog). Stimuli were presented when the obstacle was within 3° of the "frog." The distance between the obstacle and the "frog" could range between 0 and 3°. The interstimulus interval included a random element to reduce the likelihood of the child falling into a rhythm. Stimulus displacement was calculated from the midpoint between the "frog" and the obstacle. The child was asked to press a response button each time stimuli were seen. To mimic other computer games, rewards were provided for incentive. For each 10 responses to stimuli an extra game-life was added. If, however, the child was not able to overcome the obstacle presented, she/he would lose a game-life and a lose-sequence, associated with the obstacle presented, would be displayed. During this sequence, response to stimuli presentation remained active.

To be able to present stimuli at higher eccentricities, the central game was presented at different areas on the monitor. A schematic of the game sequence procedure and real-time illustrations are shown in Supplementary Annex S1.

False-positives (FP) were collected based on a combination of catch trials and response times. False-positive catch trials were tested by presenting an obstacle without an associated stimulus presentation. To discourage the child from pressing the response button each time an obstacle was presented, the game controls would become inactive and a negatively-associated sound would play each time a child performed a FP response. Response times below 180 ms, minimum physiologic time required to process the visual information and press the button, or above a response window were also considered FPs.

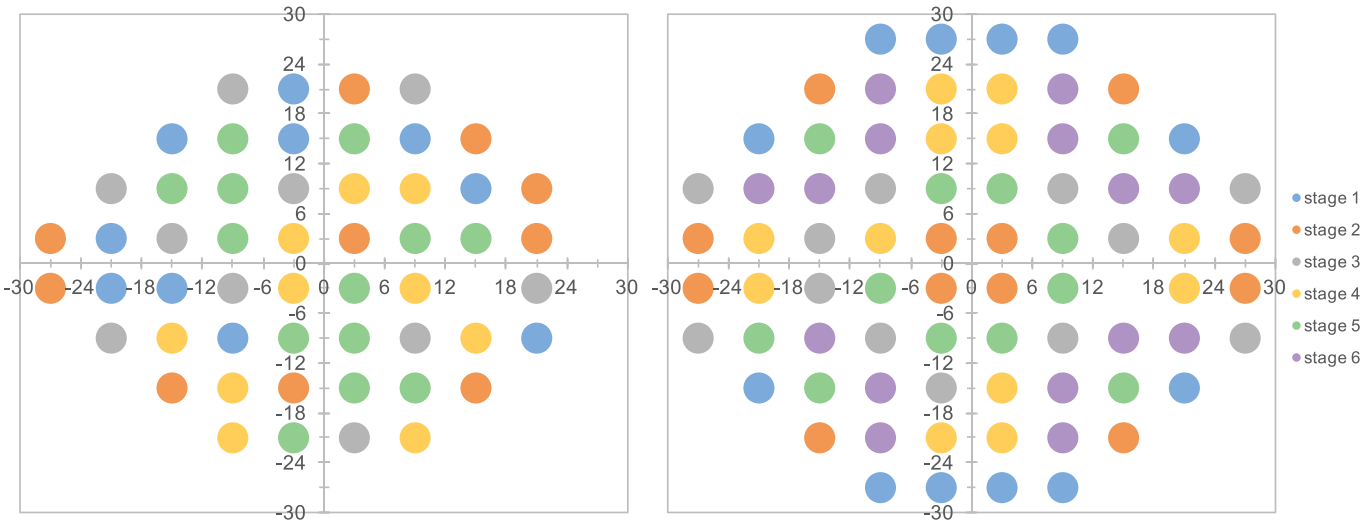

Figure 5. Test pattern and pseudo-randomization used while screening for glaucoma (*left*, 5-stage procedure) and neurological (*right*, 6-stage procedure) disorders. Within each stage, locations are presented randomly. Once a criterion has been reached, healthy or unhealthy following a 2 out of 3 rule, the next block of locations is tested. The test can be stopped at the end of each stage or, if the child still is cooperating, proceed to the next stage.

Test Strategies

Two test strategies were made available to the user: a frequency-of-seeing (FOS) approach and a suprathreshold test strategy.

Data collection using an FOS technique is traditionally lengthy, though with the advantage of providing information on threshold sensitivity and variability using data from the same test. The estimated threshold obtained from FOS data is more accurate than those estimated using staircase methods[37–39] and it generally is considered the reference standard.[37] An adaptive FOS was used to test the feasibility of using such technique in obtaining a normative database. Since variability and retinal sensitivity are unknown on the targeted population, a user interface was developed to provide the experimenter with continuous feedback on the patients' responses, total number presented, and seen at each stimulus area. Using the user interface, the experimenter was able to adjust the range of stimulus areas presented and the total number of presentations per area without interrupting the test. The aim was to ensure that response range approached 0% and 100% seen, and that the data were concentrated around the shoulder regions of the FOS curve.

A 2 out of 3 suprathreshold strategy, ideal compromise between precision and time necessary to perform the measurements,[40] was made available for screening once the normative database was developed. To minimize test times a pseudo-random test strategy was used (Fig. 5). Those locations that provide the highest amount of information were tested first[41] and were chosen based on informational value for glaucoma and neurologic conditions. For glaucoma, a 24-2 pattern is used, while for neurologic conditions a 30-2 strategy is used.

Clinical Evaluation

To test the feasibility of the test and identify areas of potential further improvement, 20 participants (4–16 years old) with no history of VF defects were recruited from the ophthalmic clinics at Manchester Royal Eye Hospital. Participants were either family members of patients undergoing treatment at Manchester Royal Eye Hospital, or patients seen attending the orthoptics' clinics of the same hospital. The study followed the tenets of the Declaration of Helsinki. Informed consent and assent were obtained from the legal guardian of the subject and the subjects themselves (respectively) after explanation of the nature and possible consequences of the study. The research was approved by the North West Lancaster Research Ethics Committee.

After the trial commenced, a demonstration was provided to the participant and the storyline was unfolded. During the demonstration period, the experimenter was able to control the onset of stimulus presentation and the stimulus area to be presented. Once the experimenter established that the subject was correctly interacting with the game and respond-

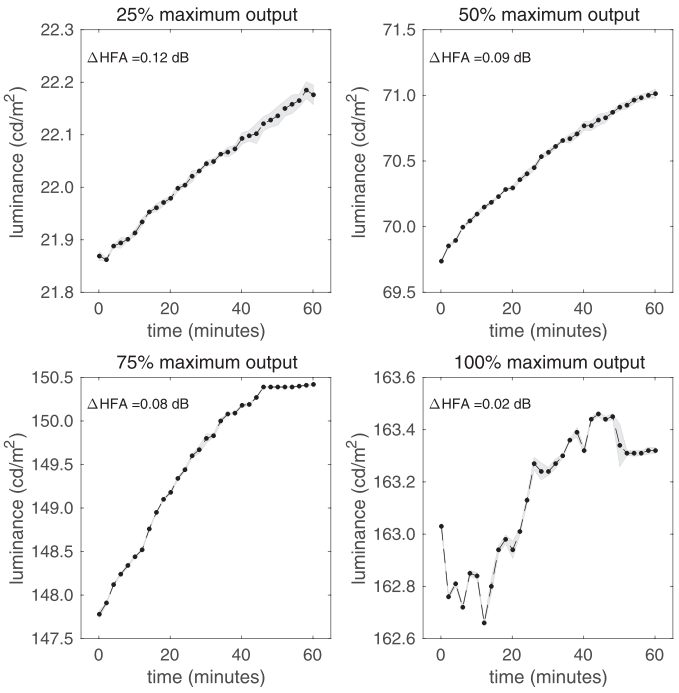

Figure 6. Changes in luminance throughout 1-hour period. Measurements were performed every 2 minutes at 25, 50, 75, and 100% of the monitor's maximum output. ΔHFA represents the difference between maximum and minimum luminance obtained converted into HFA equivalent dB units for a constant background of 10 cd/m^2 and maximum luminance of 3183 cd/m^2. The *gray area* represents the 95% confidence interval ($t_{[0.025,4]}*\sigma/\sqrt{5}$) for each set of measurements obtained at each time point.

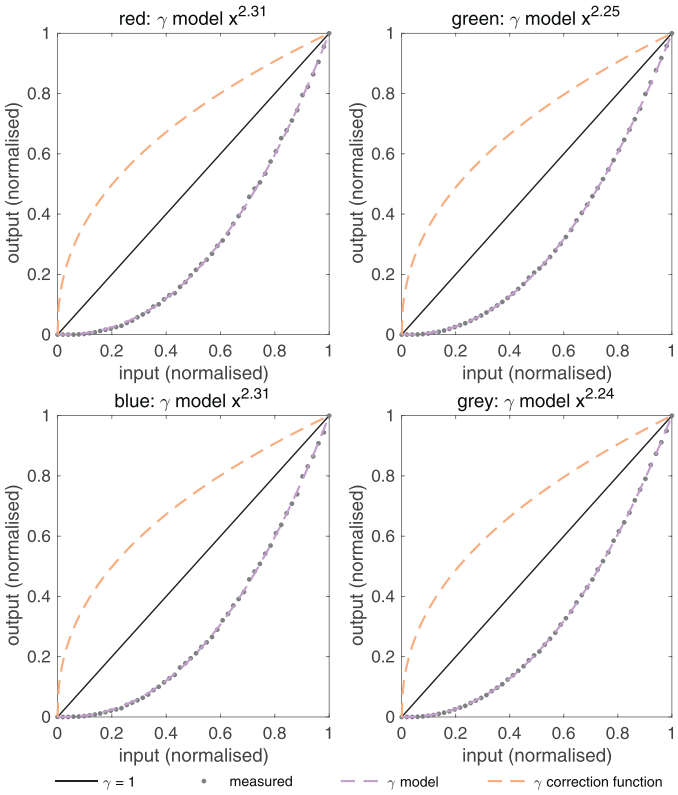

Figure 7. Gamma obtained by the OLED screen and correspondent correction function for the *red*, *green*, and *blue* channels and *gray* output. Normalised luminance values and calculated γ function are presented in *blue* (*dots*) and *red* (*line*), respectively. The inverse of the γ function is presented in *green* (*line*). Using the inverse γ function input will compensate for the observed γ and produce a linear relationship between input and luminance output - γ of 1 (*black line*).

ing to stimuli presentations appropriately, the trial commenced. For the trial, a FOS approach was used with stimuli areas being tested at two locations of the VF of one randomly chosen eye. Distractors were placed at nontest locations to avoid predictability. Distractors and test locations could be pooled from the range:

$$(-27, \pm 03), (+03, \pm 03), (-09, -15) \text{ and } (+15, +27)$$

The FOS curves were fitted to the psychometric data using MatLab and the modelfree toolbox version 1.1, which implements a nonparametric approach described by Zychaluk and Foster.[42] Threshold sensitivity, defined as the inverse of the detection function at the 50% seen-level, and variability, range between the 25% and 75% seen-levels, were determined.

When refractive correction was required, children were tested with their spectacles on. The test was stopped when the child expressed a wish to stop playing the game, or when the experimenter perceived a loss of interest from the child in playing game.

Values are presented as mean ± standard deviation unless stated otherwise.

Results

Equipment Calibration

As predicted, changes in luminance with monitor temperature were small throughout a 1-hour period for all output levels (Fig. 6). The maximum variability, difference between maximum and minimum luminance observed within an hour, was found at 75% of the maximum output. Humphrey Field Analyzer-based Δ contrast, calculated as $|HFA_{max} - HFA_{min}|$, varied the most at 25% of the monitor's maximum output.

The γ produced by the OLED screen was equivalent to the nominal γ specified by the manufacturer (Fig. 7). All three channels produced similar

Table 1. Stimulus Duration, Rise Time and Fall Time of the OLED Monitor Measured with the OTR-3

Monitor Location	Stimulus Duration, ms	Rise Time, μs	Fall Time, μs
Top left	211.84 ± 0.01	129.92 ± 5.85	53.74 ± 1.78
Central midline	211.82 ± 0.01	125.90 ± 5.82	56.15 ± 2.15
Bottom right	211.84 ± 0.01	148.07 ± 7.39	53.02 ± 1.81

Values are presented as mean ± standard error of the mean in milliseconds (ms) for stimulus duration and microseconds (μs) for rise and fall time.

γ of power ranging from 2.25 to 2.32. The γ correction function of the gray channel was used throughout the game. Background luminance varied with viewing angle from 9.2 to 10.4 cd/m^2 (9.9 ± 0.3 cd/m^2), while stimulus luminance ranged from 14 to 15.8 cd/m^2, equivalent to a HFA contrast range of 27.7 to 28.2 dB (27.9 ± 0.1 dB).

Small differences between the nominal stimulus angle subtended and that produced by the screen were observed, with a mean error of 0.018° ± 0.008°. The visual angle produced on screen was invariably smaller than the angle intended by design.

Stimuli were programmed to be presented for 12 frames at the nominal frame rate of 60 Hz. However, small variances in the monitor's refresh rate produced stimuli that were on average one frame longer than intended. Stimulus duration was stable throughout the measured areas of the monitor (Table 1). PTB seems to slightly overestimate stimulus duration (mean ± standard error of the mean): top left portion of the monitor – 216.95 ± 0.04 ms; central midline of the monitor – 216.94 ± 0.08 ms; bottom right region of the monitor – 216.83 ± 0.11 ms. A statistical significant difference was observed between the two techniques, OTR-3 and PTB ($P < 0.001$), with a mean difference of 5.07 ms. No differences were detected between the different areas of the monitor using both techniques ($P = 0.992$).

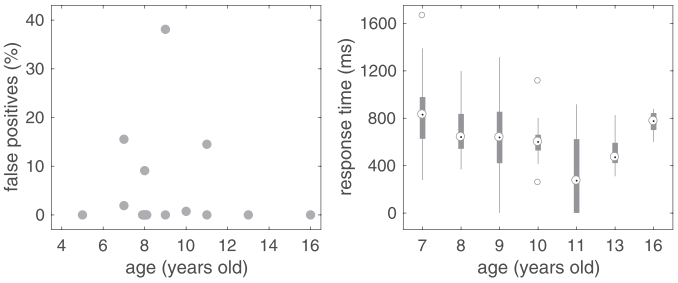

Figure 8. *Left*: False-positives plotted against age. *Right*: Median response time plotted against age. *Circle with central black dot* represents the median, *box* the interquartile range, *whiskers* 1.5 times the interquartile range, and *circles* outliers. All collected response times are presented, even those that were marked false-positives.

Clinical Evaluation

Of the 20 subjects recruited 4 withdrew for reasons external to the project, and on 2 occasions the study was stopped due to malfunction of the headrest sensor and test software. Overall, 14 subjects completed the evaluation study; 70% of the subjects were below the age of 11 (target age group).

On average, 31 stimuli exposures per patient were presented with a mean total test time of 8.22 minutes (range, 2.78–18.24 minutes), including all sequences of the game and pauses when the child moved away from the instrument. Interstimuli interval and re-

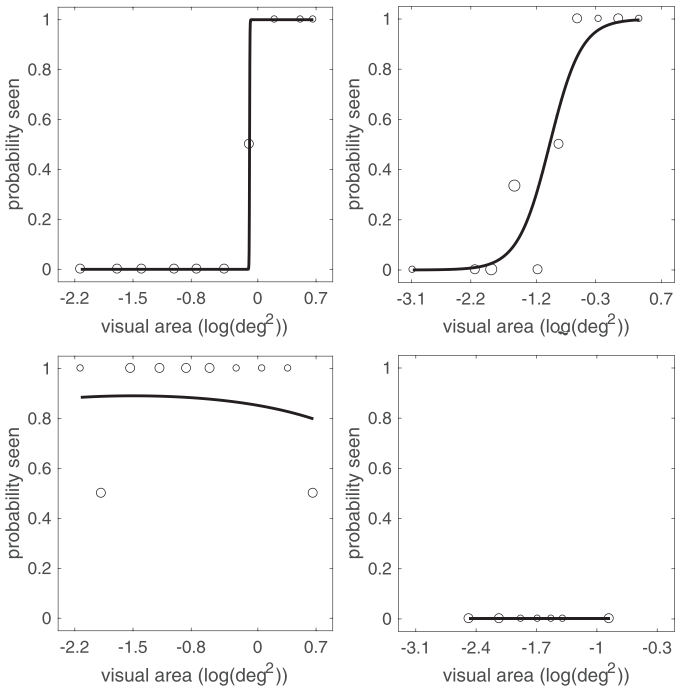

Figure 9. Example of frequency-of-seeing data obtained. *Top*: example of typical observers, one with low variability (*left*), other with average variability (*right*). *Bottom*: example of data excluded from analysis.

Table 2. Threshold and Variability for the Locations Tested Presented in Visual Area Subtended (log[deg^2]).

Field Location	Threshold	Variability
Periphery	−0.98 ± 0.25	0.74 ± 0.32
Center	−1.25 ± 0.24	0.90 ± 0.30

Thresholds represent the sensitivity value at 50% seen and variability represent the difference between the sensitivity levels at 75% and 25% seen. Values are shown as average ± standard error.

sponse window were on average 13.12 ± 15.50 and 1.55 ± 0.82 seconds, respectively.

As in adults, false-positive rates were participant-dependent (Fig. 8, left). False-positives were independent of participants' age ($P = 0.074$). However, response times significantly varied between age groups ($P < 0.001$, Kruskal-Wallis test; Fig. 8, right).

A total of 28 FOS data sets was obtained. Data from locations that did not exceed the 50% seen-level on the FOS curve were excluded. Eighteen FOS curves were used for analysis (Fig. 9). Mean threshold sensitivity and variability are presented in Table 2. Variability is presented as the difference between the 25% and 75% seen levels to give a value in meaningful clinical units. Analysis was performed separately for central, (+03,±03), and peripheral locations of the VF. As shown in previous studies, we found a reduction in mean sensitive with eccentricity – HFA equivalent: 29.33 dB at periphery and 31.68 dB at central locations. Variability, however, reduced significantly with a reduction in sensitivity ($P < 0.001$, orthogonal least square analysis).

Threshold sensitivity was independent of false-positive rate ($P = 0.18$) and age ($P = 0.10$). Likewise, the variability observed was not associated with participants age ($P = 0.195$, Kruskal-Wallis test).

Discussion

In this study, we found that the OLED panel produced a spatial uniform background and stimuli luminance with repeatable stimulus duration. Although measured stimulus duration differed from PTB self-reported, differences were minimal and unlikely to affect clinical outcomes. In agreement with previous studies,[43] we have shown that rapid luminance transition between background and stimuli occur, making these panels ideal for visual experiments requiring high temporal precision. The high temporal precision allowed the presentation of moving targets, central game, without motion blur. Another important feature of this monitor is the small variability in luminance after the monitor is turned on (Fig. 6). Contrary to typical CRTs and LCDs, the changes in luminance observed will have a negligible impact on visual function assessment – important in clinical settings.

The benefit of using FOS strategies comes at an expense of long test duration due to the high volume of presentations, and remain challenging even in an adult population. However, our test completion success rate was similar to previous studies involving conventional strategies and a pediatric population.[44,45] During our clinical evaluation work, a smaller number of presentations were performed for a comparable test time to that presented in the literature.[46–49] The long test duration to stimuli presentation ratio is a consequence of the game strategy used, and resulted from a longer than average interstimuli interval. Perhaps due to the nature of the game, the average response window observed was also larger than in adult-based commercial available instruments.

The game procedure provided positive and negative feedback to the user. We believe this increases test experience, which outweighs the increase in test time. However, the test could be improved with the use of an eye-tracker for the automatic checking of fixation before stimulus presentations. Automatic checking potentially could speed up the test via a reduction in the interstimulus interval. Automatic checking also could provide a surrogate measure of vigilance. However, the use of eye-tracking devices will not be appropriate for all children, particularly those with development problems and those with nystagmus.

Using a computer game to test the VF of a pediatric population has been shown to provide reliable results and to be well accepted by the sample population used in this study.[7] On two occasions, participants even have asked whether they could use the system at home.

Bental and Lowe[15] have shown that children have response patterns that are influenced by the test instructions provided. The effect observed was age-dependent with younger children being influenced the most. In conventional perimetry, the task consists of pressing a button each time a spot of light is seen. It is to be expected that a higher FP rate will occur in an attempt from the child to comply with the instructions provided. An increase in FP rates has been demonstrated by Tschopp et al.,[17] and Morales and Brown.[5] Even higher rates may occur with advanced VF loss

where periods of nonseen stimuli increase. Shifting the purpose of the task to a game and contextualizing the stimuli presentation within that game may help to reduce the rates of FP responses (Fig. 8, left). With the exception of one participant, FP rates found in this study were similar to those observed in adult-based ophthalmic clinics and, in agreement with Tschopp et al.,[49] were not associated with age. Attention and fixation were controlled by the nature of the game and the desire to gain "coins" and avoid the loss of "game-lives." The subject's main goal was to successfully play the game for which gazing into other areas of the monitor would be counterproductive. Not only do catch trial techniques for determining false-negatives and fixation losses increase test time, but they also have been shown to be poor predictors of test reliability.[50,51] Response times, on the other hand, can provide good, repeatable information on subject reliability. Response times are used in the Swedish Interactive Thresholding Algorithm to derive an estimate of the FP rate, which is more consistent than catch trial estimates. Previous studies have determined a response time window of 480 to 800 ms at threshold intensities in an adult population.[48,52,53] Median response times found in this study fell within this range, with the exception of the 11-year-old age group (Fig. 8, right). In this age group, one subject produced a large number (17%) of responses below 180 ms, suggesting that the patient was perhaps trying to guess stimulus onset. A general trend for a decrease in response time with an increase in age was observed. This may suggest that younger subjects find it more difficult to divide attention between the game-strategy and the stimuli.

The threshold sensitivities obtained in this study were similar to those observed in an adult-based normative population (Table 2).[46,54] Contrary to previously reported studies,[44,45] a reduction in sensitivity with age was not observed. Adult-like sensitivity values,[46,54] range 19 to 38 dB, were observed in 7- and 8-year-old subjects. Differences observed between the studies are likely to be explained by the use of the mean deviation in the study of Patel et al.[44] and localized sensitivity in ours, or by the stimulus type used. The use of mean deviation may mask an underlying difficulty in testing VFs in a pediatric population, where children are less able to focus their attention on different targets.[16] A reduction in mean deviation in the study of Patel et al.[44] may be a byproduct of reduced attention resources rather than a true underlying difference in sensitivity. In fact, it has been shown that vigilance and attention are better predictors of threshold sensitivity than age.[49] Delaney et al.,[55] in a study investigating different flicker frequencies, suggested that differences in VF sensitivity between adults and children depend on the stimulus parameters used during testing. Visual processes involved in the detection of size modulated stimuli may also differ from those using intensity modulation. Redmond et al.[56] have found a decrease in contrast sensitivity with age for different stimulus sizes, with no observable differences in Ricco's area with age on an adult population. Since the combination of stimuli intensity and area used is likely to fall within Ricco's area, it is feasible that changes in sensitivity with age will not be observed in the present study.

Mean variability observed, 0.74 log(deg^2) at periphery and 0.90 log(deg^2) at center (7.55 and 9.01 dB), were significantly higher than the values reported previously in a healthy adult population.[46,54] An increase in FOS variability in children compared to adults has been reported previously.[49] As in the study of Tschoop et al.,[49] we found variability to be subject-dependent with subjects of the same age often having different degrees of variability. Although the variability observed is high compared to an adult's, an association between variability and age was not observed. The high observed variability may be linked to the limited number of presentations used in this challenging population. Of interest was the increase in variability with reduced stimulus size (increased sensitivity). Previous studies have shown a reduction in test variability with an increase in stimulus size.[57–59] It is important to recognize that the high variability, whether a consequence of the population being tested or the strategy used, may have introduced a sensitivity bias. Previous studies have shown that the relationship between variability and sensitivity does not occur with a size, as opposed to intensity, modulation paradigm.[60,61] Size modulation is able to detect mild-to-moderate glaucoma loss and performs as well as intensity modulation for disease detection.[62] Size modulation in perimetry has been used successfully in the past.[34,63]

The use of different levels within the game, where the speed of presentations increased, might have resulted in more attentional resources being devoted to the game with a commensurate reduction in estimated sensitivity particularly at more peripheral locations. It is also likely that the division of attentional resources may change for different age groups and with experience with computer games. However, their impact must be investigated in future

work, the similarities in conventional adult-base sensitivities and those observed suggest a limited effect.

Conclusion

This study describes a procedure to test VF in a pediatric population using a computer game. The hardware used was appropriate for the demands of the test and the test itself was well accepted by the study population despite longer test times. Retinal sensitivity was closer to that in an adult population. Test variability, on the other hand, was significant and considerably higher than in an adult normative population and remains a challenge. This finding highlights the problem of using adult-based systems in a pediatric population as most of these systems employ knowledge of variability into their test algorithm. Instead, we proposed that the test should be adapted to address the child's needs.

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