

Pediatric Perimeter—A Novel Device to Measure Visual Fields in Infants and Patients with Special Needs

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Purpose: There are no commercially available devices to measure visual fields in infants. We developed a device, “Pediatric Perimeter,” that quantifies visual field extent (VFE) for infants. We describe the construction, validation, and use of this device.

Methods: A hemispherical dome with light emitting diodes (LEDs) was constructed. The LEDs were controlled using a computer program to measure reaction time (RT) to gross visual fields (GVF) and the VFE. Participants were tested in supine position in a dark room. Eye or head movement towards the stimuli was monitored with an infrared (IR) camera. Validation was done on 10 adults (mean age: 24.4 ± 5 years) with tunnel vision simulator.

Results: Perimetry was performed on 19 infants (age: 2.3–12 months), five infants with normal milestones. GVF and VFE were estimated in 17 and 7 infants, respectively. Median RT of infants with developmental delay was 663 ms and 380 ms for healthy infants. Also, 14 children (age: 14 months–6 years) with developmental delay and five patients with cognitive impairment were tested.

Conclusion: Visual field isopter and RT can be examined with the Pediatric Perimeter device on infants and patients with special needs. Further testing on infants will need to assess the repeatability. A large-scale study will be needed to compare typically developing infants and infants with delayed milestones with this device.

Translational Relevance: Quantifiable parameters obtained with this device can be used as outcome measures in clinical examination of infants and patients with special needs. This device can be used in pediatric, neurology, and ophthalmology clinics.

Perimeters are useful, non-invasive diagnostic tools to detect disorders of the visual pathway. While varieties of perimeters are available for adults, no commercial perimeter device is available for infants (age, 0–12 months). Even testing young children (age, ≥4 years) still remains a challenge.^{1,2} Infants and children with neurological impairments (e.g., neonatal encephalopathies) are known to have visual field defects.^{3,4} It has been reported that in otherwise healthy individuals, visual field defects arising during infancy gets detected only in adulthood.^{5–7} Early detection of visual field loss, besides being of diagnostic value, can help in better medical management and/or in the rehabilitation for the child.

In clinical practice, visual fields of infants are typically assessed by bringing bright toys from the periphery and seeing if it attracts the infant’s visual attention. Visual attention is determined by the clinician observing for meaningful eye and or head movements of the infant in the direction of the target. While this confrontational perimetry procedure is quick and easy, there exists no accurate objective quantification of this measurement, namely the visual field extent (VFE). Some clinicians and researchers have successfully quantified visual fields in infants using the Goldmann perimeter, White Sphere Kinetic Perimeter (WSKP), or the double arc light emitting diode (LED) perimeter by observing the infant’s eye

or head movement, particularly in the cardinal visual field meridians (45°, 135°, 225°, 315°).^{8–10} The behavioral visual field screening test is a similar technique that uses a white ball with a semicircular arc and was tested in individuals (age: 4 months–27 years) with neurological impairment.¹¹ Few other studies on visual field testing in infants or children with neurological impairment have also used the behavioral measures of preferential looking.^{12,13} The devices used in these studies for visual field quantification (e.g., Goldmann perimeter and double arc perimeter) are not readily available; thus, leaving a gap in clinical care.

In this paper, we report a newly developed device referred as “Pediatric Perimeter” that can be potentially used in clinical settings. The first prototype for this device was conceived in a week long rapid prototyping workshop conducted in India as a collaborative effort between L V Prasad Eye Institute (LVPEI) and the Massachusetts Institute of Technology’s Media Lab, Camera Culture Group, in 2013. The second and the third prototype were then subsequently and systematically built in the time frame 2014 to 2015. The construction, working, validation, and testing of the Pediatric Perimeter (prototypes II and III) is described. We have been able to use this device to quantitatively estimate the visual fields for infants and also on patients with special needs for whom testing was not possible with conventional perimeters.

Methods

The institutional review board of LVPEI approved the study protocol. The testing adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained (including consent for video recording) from the participants and patients who were above 18 years of age and from parents or caretakers of those participants who had cognitive impairment or who were less than 18 years of age. When possible, verbal assent was also taken from this latter group. Visual acuity and refractive error measurements of the participants were taken from their clinical records. Participants were tested in their habitual viewing condition.

Construction of the Device

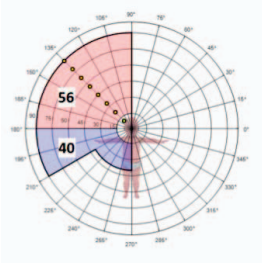
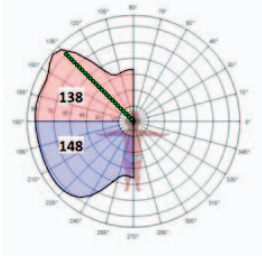
Hardware

A total of three prototypes were built serially improving upon the features and functions of the earlier versions. Prototypes II and III were used to

obtain data and will be described (Table 1). Both these prototypes have a hemispherical dome built with a steel skeleton having 120-cm diameter. This dimension was chosen to comfortably place the infant in a supine position. A black cloth covered the dome and the metal rods were padded with foam. The dome was divided into 24 equidistant meridians at angular intervals of 15° in the azimuthal direction (Fig. 1). LEDs placed along the meridians were displayed sequentially from periphery toward center, as done in hybrid perimetry (static-kinetic perimetry).^{10,14} The viewing distance from the infant to the central fixation and to the rest of LEDs was 60 cm for prototype II. For prototype III, we accounted for the different head sizes (occipital distance) in the algorithm, and the position of each LED (x, y, z) was calculated for each participant in order to map the precise location of the stimulus. The color setting for the RGB (red, green, blue) LEDs was set to match 550 nm using hexadecimal (#a3ff00) color conversion (<https://academo.org/demos/wavelength-to-colour-relationship/>). The chosen wavelengths in both the prototypes were closer to the human peak spectral sensitivity (V_λ peaks at 555 nm).¹⁵ It is known that infants’ scotopic and photopic spectral sensitivity curves are similar to adults.^{16–19} The luminance of the LEDs was set to 30 cd/m². This value was determined by subjectively measuring the luminance of the LED that did not cause scatter when projected on the blind spot of two adult subjects (PNS, SD). Testing was done in dark room (0.1 cd/m²) mesopic-scotopic conditions.²⁰ An IR camera mounted at the apex of the dome provided a live video feed of the tested infant to the examiner’s computer. Similar to previous studies,^{10,11} detection of the peripheral target by the infant is registered by the examiner, upon observing the video of the infant’s eye/head (gaze) movement toward the target. Unlike the previous studies, the examiner knew the position of the target in this testing. However, because the testing was video recorded it allowed independent verification for detection responses at a later time by another examiner (also a trained optometrist) to avoid bias. An excellent agreement (intraclass correlation = 0.9) was obtained between the two independent examiners from analyzing 20 pilot sample videos.

Measurable VFE in superior, left, and right quadrants of the dome was 90°. VFE of the inferior quadrant was only 40°, because the entrance to the dome for positioning the infant for testing was placed in this quadrant in prototype II. In prototype III, two entrances were provided to facilitate entrance and exit

Table 1. Description of Prototypes II and III

	Attributes	Prototype II	Prototype III
Device Construction	Camera	Microsoft Life Cam 640x480 @ 30 fps	HD USB Camera (ELP-USBFHD01M) 640x480 @ 60 fps
	IR LEDs Type	Vishay Semiconductors, TSAL6400 (940nm)	Vishay Semiconductors, TSAL6200 (940 nm)
	Peripheral LEDs	5mm, Yellow LEDs (580nm), 30 cd/m ²	RGB LED (3mm) Strips (WS2812B), Green (550nm), 30 cd/m ²
	Fixation LEDs	5mm, Yellow LEDs (580nm), 25 cd/m ² (4 in number)	5mm, Yellow LEDs (580nm), 25 cd/m ² (2 in number)
	Spatial resolution of 2 LEDs in a meridian	10°	3.5°
	Sliding silhouette mattress tray	Absent	Present
	Calibration / Testing Conditions	Time Lag (T camera + T led)	257.08 ± 46.70 ms
Angular velocity of the kinetic stimulus		10°/s (fixed)	3.5°- 10°/s (variable)
Frame capture rate of the video		15 frames/second	25-35 frames/second
"Fixation patterns" to make the child look towards the fixation point		Absent	Present
Visual Field Extent & LED distribution (in a meridian) is shown. Number of LEDs in a Quadrant is written on the figure (<i>the other hemifield is symmetrical</i>)			

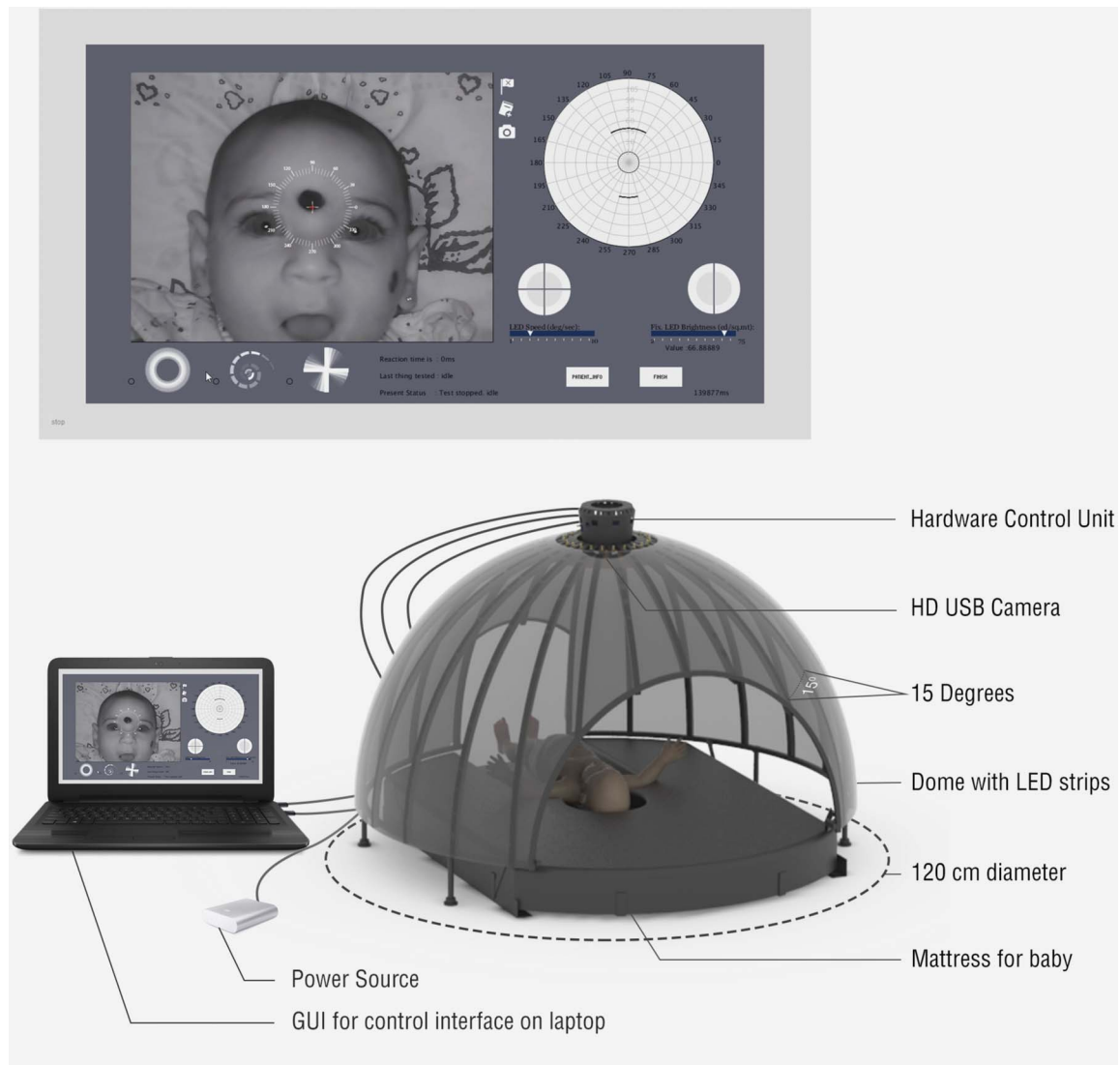


Figure 1. Schematic diagram of the Pediatric Perimeter device (prototype III), showing the skeletal structure of the hemispherical dome. The magnified screen snapshot of an infant getting tested and the GUI is also shown. Informed consent has been obtained from parents to publish the image of the infant.

for both infants and adults. With this design, 50° to 60° VFE in the inferior field and 40° to 50° in the superior visual field can be obtained depending on the range (10–20 cm) of the occipital distance.

Software

A computer program written in the open-source Processing v2.0 software controlled all the LED stimuli depending on the testing algorithm selected by the examiner. A computer laptop (Acer Aspire E15, Intel core i5 processor, 4GB RAM, Windows 7 for prototype II and Intel core i3, 8GB RAM, Windows 10 for prototype III) was used to run the program that controlled the testing algorithms via a

graphical user interface (GUI; Fig. 1). Table 1 gives the technical specifications of the two prototypes. Essentially prototype III had enhanced GUI features and additional functionalities (e.g., patterns to encourage an infant's fixation to center, flexibility to change the speed of target presentation in hybrid perimetry, and to change the luminance of the LEDs). Two testing algorithms were developed and are explained below.

Gross Visual Field Test

The Pediatric Perimeter permits checking for gross visual fields (GVF; hemisphere or quadrants of the visual field) with the aim to detect GVF defects

(hemianopia or quadrantanopia). From now on we will be calling the hemispheres and quadrants of the visual field as hemifield and quadrafield. In this test, LED stimuli in the hemifields or quadrafields were displayed by selecting the tested side with a mouse click from the GUI. In order to avoid scatter into the non-tested field, the LEDs in the central 30° diameter were not displayed. In general, right hemifield was tested first followed by left hemifield and followed by the quadrants (right up, right down, left up, or left down). When the infant responds to the stimuli by making an eye and/or head turn in the appropriate direction, the examiner registered the response with a key press. The trial was terminated if no response (no eye or head turn) was observed for a period of 15 seconds or if a response was made in a wrong direction. A particular quadrafield or hemifield was repeated if the examiner was unsure about the response.

Reaction Time (RT)

Reaction time (RT) is the time taken for the infant to look at the stimulus after its onset. RT was calculated as the time interval between stimuli presentation by the examiner and key press registration by the examiner in the GVF test upon detection of the purposeful eye/head movement in the infant. While this is a straightforward measure, intrinsically there are few components to it. The total RT as measured by our computer program can be broken down into the following components:

$$T_{\text{TOTAL}} = T_{\text{REACTION_INFANT}} + T_{\text{REACTION_EXAMINER}} + T_{\text{CAMERA_LAG}} + T_{\text{LED_ON}} \quad (1)$$

T_{TOTAL} is the total time taken from the stimulus onset to when the infant's response got registered. $T_{\text{REACTION_INFANT}}$ is the time taken by the infant to make an eye or head movement toward the stimuli from the time it was turned on and is the parameter that is of prime importance. $T_{\text{REACTION_EXAMINER}}$ is the examiner's determination of the eye or head of the infant to the presented stimuli, and the subsequent registration of the same by the examiner through a keyboard press. The time taken by the camera to capture each video frame is termed as the $T_{\text{CAMERA_LAG}}$ and the time taken by the LEDs to turn on after we click a button in the GUI is called as $T_{\text{LED_ON}}$. The time delays introduced by the electronics in the system (i.e., $T_{\text{CAMERA_LAG}}$ and $T_{\text{LED_ON}}$) can be measured experimentally. We positioned a photodiode in front of the computer

that displayed the GUI screen. A mirror was positioned below the IR camera to provide the video view of the lighted LEDs. Upon clicking the computer mouse on the GUI for hemifield, the LEDs were turned ON. This video image of the bright LED produced a voltage change for the photodiode. We measured the voltage of the mouse button click and the bias voltage across the photodiode with an oscilloscope (RIGOL DS1102E; Rigol Technologies Inc., Beijing, China). The time lags of the two prototypes are given in Table 1.

$T_{\text{REACTION_EXAMINER}}$ is a subjective quantity, which is dependent upon the examiner. In the present study, we used Datavyu video analysis software (version 1.2) to estimate RT through a frame-by-frame manual analysis (Fig. 2), and therefore this human-dependent parameter was neglected. The initiation of the eye/head movement was taken into consideration, corrected RT was obtained by taking the timestamp of each testing from the post hoc analysis of the videos from Datavyu software and then subtracting 257 ms from it for prototype II and 239 ms for prototype III to account for the delay in the electronics.

Visual Field Extent Test

To measure the VFE, hybrid perimetry was done by sequentially displaying the LED stimulus (luminance 30 cd/m²) along each meridian.^{10,14} LED light stimulus was presented from the periphery toward the center at 10°/s for prototype II and at 3°/s in prototype III. Earlier studies^{14,21} recommend a 2° to 3°/s for stimuli speed, as was used in prototype III. For prototype II with a wider spatial resolution (LEDs 10° apart), 10°/s was found to be more suitable rather than a lower speed, where infants were losing interest quickly. In general, the cardinal meridians (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) were tested first and the remaining meridians were tested subsequently in no particular order. The fixation LED was turned off when the LED stimulus in a meridian was presented. As soon as the examiner detected the infant's gaze toward the LED stimulus, a key was pressed to register the response and the next meridian was tested, thus populating the data points to eventually generate the visual field isopter. No response was registered when the infant misses the stimulus or if they looked away in the wrong direction. If and when required, a particular meridian testing could be repeated and the data stored sequentially.

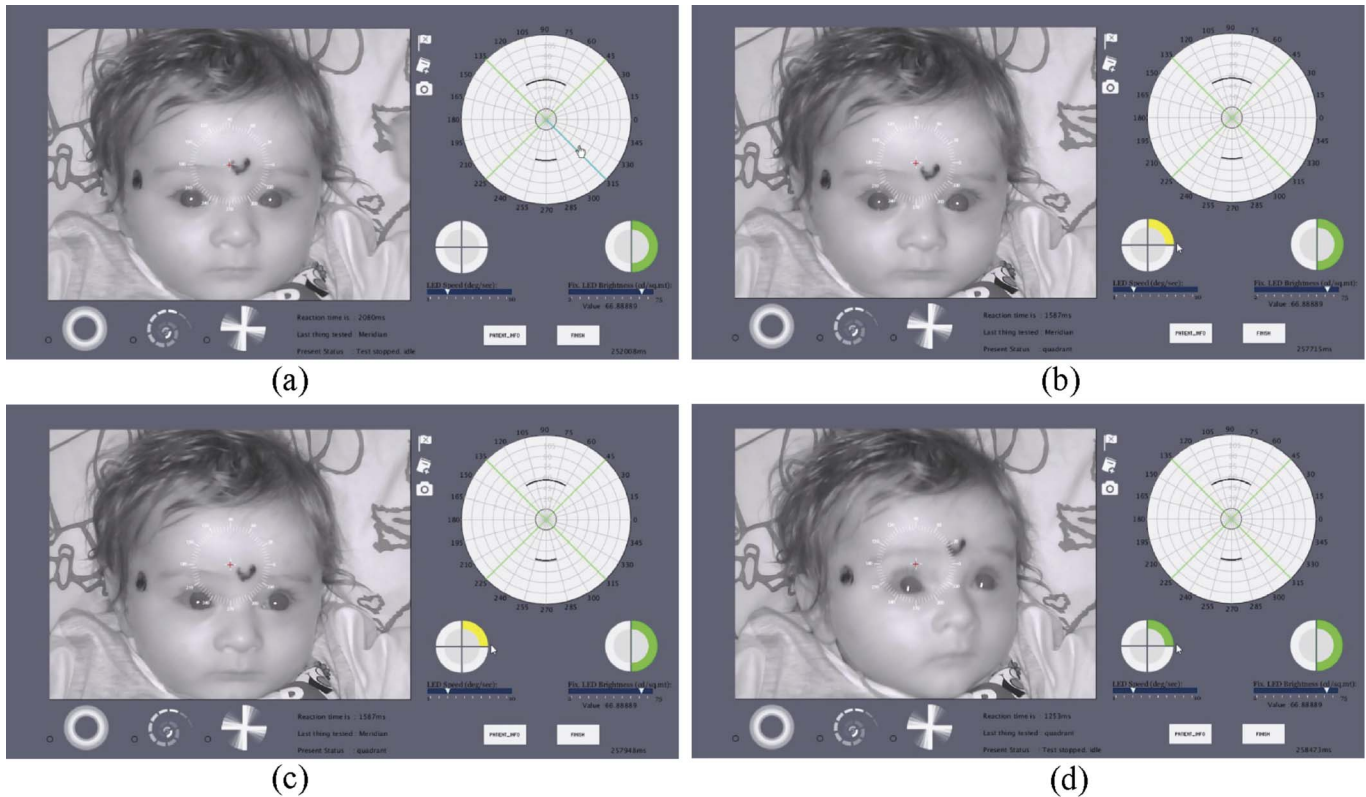


Figure 2. Illustration of video frame analysis with Datavyu software. (a) Infant fixating straight. (b) Quadrant stimuli (yellow) are presented. (c) Infant initiating an eye movement toward the stimuli. (d) Infant completing the fixation gaze (eye and head movement) toward the stimuli. Examiner registers the response (color change to green). Time difference between (b) and (c) is used to calculate reaction time. Informed consent has been obtained from parents to publish the image of the infant.

Validation Study

Ten adults (average age: 24.4 ± 5.1 years) with normal visual status (visual acuity 20/20 or better and full visual fields) were made to wear a tunnel vision simulator goggle, which only allowed a visual field radius of 16° . With one eye (non-dominant) patched and wearing this goggle, these participants were tested with the Pediatric Perimeter device in supine position. Participants gave verbal response to the examiner when they detected the peripheral light stimuli. Three of these participants were also tested on the kinetic mode of Humphrey Visual Field analyzer (HVF; HFA3, Zeiss, Germany) for comparison. Three adult patients, one with glaucoma (22/m, visual acuity 20/20⁻²), one with retinitis pigmentosa (28/m, 20/400), and another with homonymous hemianopia (42/m, 20/20) also participated in the study. The glaucoma patient made an eye/head turn toward the stimuli and the other two patients gave verbal response upon detection of the peripheral stimuli. These patients were tested on both the Pediatric Perimeter and the

kinetic mode of HVF in a random order. Manual kinetic mode was used in measuring the VFE of the participants in HVF. The speed of the target (Goldmann size III4e) in the kinetic mode of HVF was kept at $2^\circ/s$. The background illumination used was 31.5 asb. The stimulus was moved from non-seeing area to seeing area. The area of the visual field found by the Pediatric Perimeter and HVF were compared using a MATLAB (R2007a; Mathworks, Natick, MA) program that fit a polygon. All the validation tests were done with prototype III.

Testing Infants and Patients with Special Needs

Infants were placed in supine position on the mattress and were slid into the dome of the Pediatric Perimeter device. With the silhouette cutout in the mattress and with a neck pillow (if needed), head movements were restrained. In prototype II, only the neck pillow was used to restrain the head movement. The parent or the caretaker was kept by the infant's

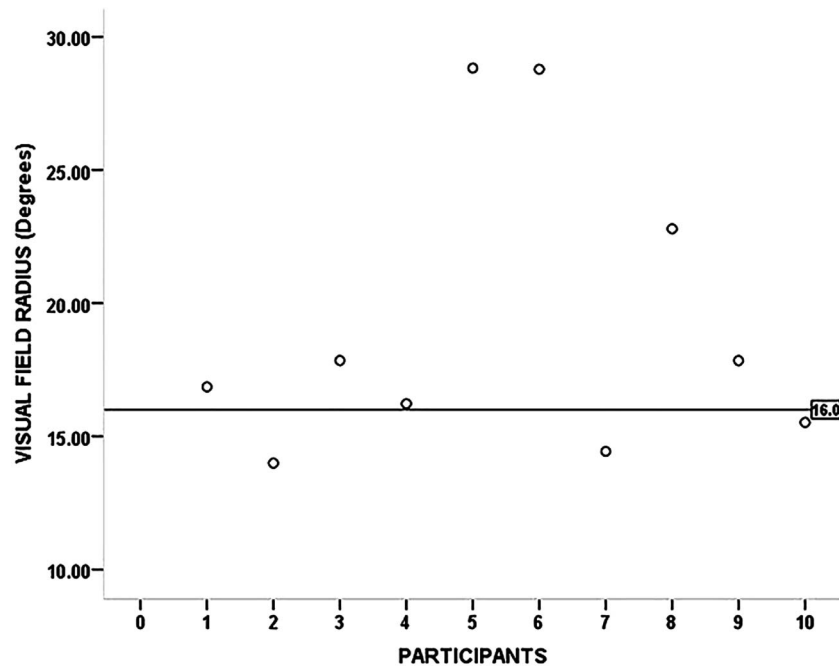


Figure 3. Scatter plot showing the visual field radius of 10 participants with the tunnel vision simulator. The expected visual field radius (16°) is marked as a solid line.

(or patient's) side outside the dome, with their hand constantly touching the participant's feet to give reassurance. The room lights were kept on, until the infant went into the dome, then the fixation lights were turned inside the dome and the room lights turned off. When the infant was comfortable inside the dome, testing began else fixation patterns were turned on that displayed different colored LEDs to attract the infant's attention. The infant's position was adjusted before the testing procedure by aligning a central red cross in the GUI between the two eyes (Fig. 1). All the tests were carried out binocularly. The test was paused as needed to realign the infant with the central cross when they changed their position. The GVF test was performed first and the VFE was measured next. The testing position and procedure was similar for patients with special needs.

Results

Validation Study

The average empirical radius of the visual field measured with the tunnel vision simulator goggle was $19.31^\circ \pm 5.36$. This was larger than the theoretically calculated visual field radius of 16° (Fig. 3). One example video for the validation testing with the tunnel vision simulator is shown in [Supplementary](#)

[Material \(Supplementary Video-S1\)](#). On three participants who had their visual fields tested on both the Pediatric Perimeter and HVF the mean radius was found to be 19.43° and 16.22° , respectively.

The visual field isopters obtained with the Pediatric Perimeter and HVF on the three adult patients (Fig. 4) were compared in two ways. First, the overall area of the visual field was calculated and the radius of the visual field was obtained with each device. The average (\pm standard deviation) difference in the radius between the Pediatric Perimeter and HVF was found to be $10.53^\circ (\pm 0.8)$. Next, the intersection and union area of the visual field isopters obtained from the two devices were plotted in a similar way as mentioned in an earlier study.²² As the kinetic mode in HVF presented the stimuli from different peripheral extents, the visual field isopter of the Pediatric Perimeter was trimmed to match this extent. The percentage of intersection area to the union area was found to be 71.2% (in patients with glaucoma), 31.6% (patients with retinitis pigmentosa), and 19.5% (in patients with hemianopia).

Testing Infants

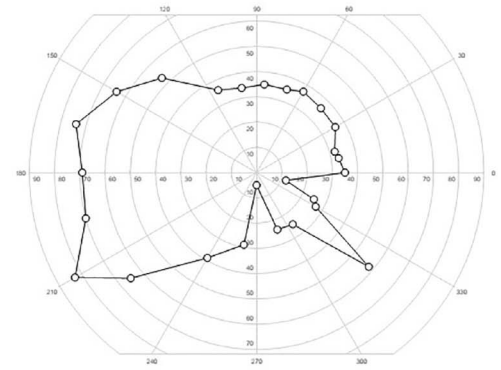
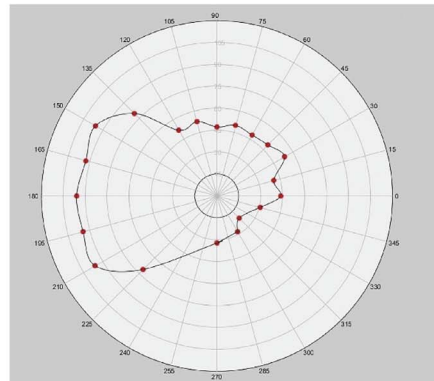
A total of 19 infants participated of which 5 infants had normal milestones and 14 had developmental

Patient Condition

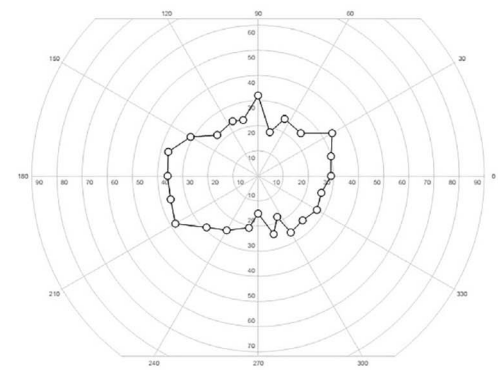
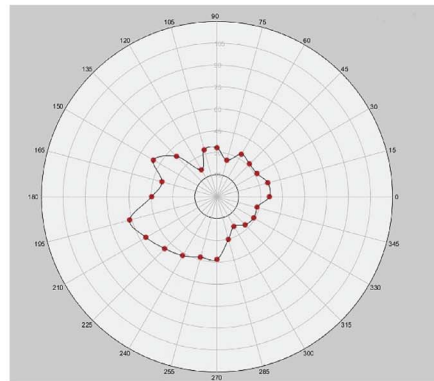
Pediatric Perimeter

HVF

Glaucoma



Retinitis Pigmentosa



Right Hemianopia

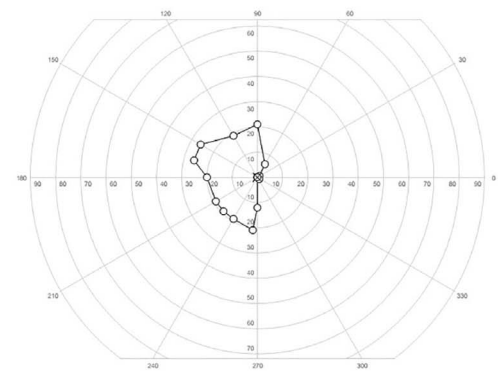
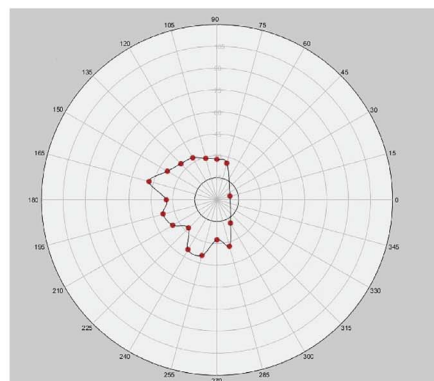


Figure 4. Visual field isopters obtained with the Pediatric Perimeter and HVF device on three patients. The radial spacing of the circles are 15° and 10° in the Pediatric Perimeter and HVF, respectively.

delay. The diagnosis in infants with developmental delay included hypoxic ischemic encephalopathy, cortical visual impairment, retinopathy of prematurity, and optic atrophy. None of the infants wore any spectacle correction. Visual acuity could not be measured for the infants with developmental delay with Teller Acuity charts. All the healthy infants

could fixate and follow light and other nonilluminated small toys, Teller acuity test was not attempted on them. All the tested infants were comfortable under the dome and the testing time (includes breaks) varied from 6 to 32 minutes. The number of repeated trials by an examiner varied from one to five for GVF test. Some infants were tested in prototype II ($n = 16$)

Table 2. Distribution of the Number of Participants and the Number of Meridians Tested in the Visual Field Extent Test

Tested Group	Age Range	Visual Acuity	GVF	Number of Participants Responding			Median RT to GVF [Interquartile Range] (Number of Participants)
				1–4 Meridians	5–8 Meridians	9–24 Meridians	
Infants with normal milestones (<i>n</i> = 5)	6–11 mo	FFL	5	1	1	3	380.5 ms [270–446] (<i>n</i> = 5)
Infants with developmental delay (<i>n</i> = 14)	2–12 mo	FFL (<i>n</i> = 7); occasionally FFL (<i>n</i> = 4); only fixation (<i>n</i> = 2); doesn't fixate (<i>n</i> = 1)	12	6	1	2	663.5 ms [448–1974] (<i>n</i> = 7)
Children with developmental delay (<i>n</i> = 14)	14 mo–6 y	(BE) 20/190 with TAC at 55 cm (60% reliability); FFL (<i>n</i> = 5); occasionally FFL (<i>n</i> = 3); only fixation (<i>n</i> = 4); doesn't fixate (<i>n</i> = 1)	13	5	4	4	1255 ms [1066–2794] (<i>n</i> = 6)
Patients with cognitive impairment (<i>n</i> = 5)	9–18 y	20/80–20/20	5	-	2	3	3866.2 ms [1212–6549] (<i>n</i> = 5)

FFL, fixates and follows light; BE, both eyes; TAC, Teller Acuity Cards. Median reaction time (RT) to gross visual field test (GVF) measured in milliseconds (ms) from those participants who had reliable responses from the video analysis is shown in the last column.

and few on prototype III (*n* = 3). Example videos ([Supplementary Videos S2](#) and [S3](#)) of testing in both the prototypes are shown in the [Supplementary Material](#).

The two infants with developmental delay who did not fixate and follow light in their clinical examination responded to the GVF test. On the other hand, two infants with developmental delay did not respond to the GVF test and their clinical record documented occasionally fixates and follows light. RT was calculated from those infants who had reliable responses to GVF test, upon reviewing the videos. The VFE was also measurable in some infants. [Table](#)

[2](#) shows the RT and the number of visual meridians tested in the VFE test for the different group of participants. [Figure 5](#) shows illustrative examples of visual field isopters obtained from three participants.

Testing Children with Developmental Delay

We also tested 14 children with developmental delay ([Table 2](#)). These children had similar diagnoses as that seen in infants with developmental delay. These children were referred from our Early Intervention department. On each prototype (II and III), seven children were tested. Thirteen participants of 14

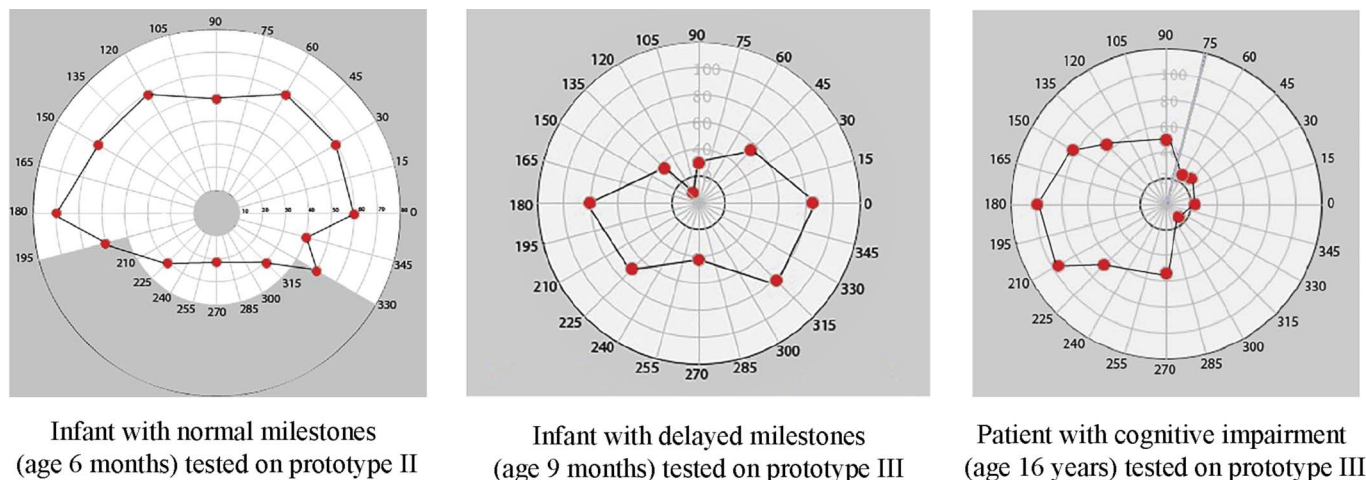


Figure 5. Visual field isopters obtained from the Pediatric Perimeter device on three participants.

responded to the GVF testing. Meridian testing was possible in 8 of 14 participants. The testing time varied from 10 to 35 minutes.

Testing Patients with Cognitive Impairment

Five patients (age, 9–18 years) diagnosed with refractory occipital lobe epileptic seizures and cognitive impairment were referred for perimetry from a neurosurgeon. These patients were to undergo a brain surgery for controlling their epileptic seizures. Attempts of testing them on HVF were unsuccessful, and hence were referred. We attempted testing them with tangent screen perimeter and were unsuccessful. All of the patients were able to perform the visual field testing when tested with the Pediatric Perimeter. Four of five patients had full visual fields, one patient appeared to have a right hemianopic visual field defect (shown in Fig. 4). Such an impression was observed with confrontational perimetry as well. A segment of the video testing (Supplementary Video S4) for this patient is shown in the Supplementary Material.

Discussion

Measuring visual fields in infants and in patients with cognitive impairment is very challenging. The Pediatric Perimeter device described here (both the hardware and the software) attempted to address this challenge to a great extent. All of the participants recruited for this study were comfortable in getting tested with this device. However, their endurance to complete the full testing that includes GVF test (4 quadrants and 2 hemifields) and VFE test (24

meridians) varied as can be seen in Table 2. Of the total 38 participants (19 infants, 14 children with developmental delay, and 5 patients with occipital lobe epileptic seizure and cognitive impairment) tested, with strict video reviewing criteria, we were able to get a reliable estimate for RT with GVF on 60.52% (23/38) of the participants (100% on infants with normal milestones and patients with cognitive impairment, 50% of infants with developmental delay, 42.85% on children with developmental delay) and plot the visual field isopter (more than 4 meridians tested) on 52.63% (20/38) of the participants (80% of infants with normal milestones, 100% of patients with cognitive impairment, 21.42% and 57.14% of infants and children with developmental delay, respectively).

In the present work, we show a proof of concept that more meridians (beyond the cardinal meridians) can also be tested in infants and a complete visual field isopter (more than 4 tested meridians) can be plotted in one sitting, without having the need for the infant to come on multiple visits. Unlike the other perimetric testing in which the infant is in sitting posture or in the “flying baby” position for the visual field testing, the supine position in the Pediatric Perimeter testing in an enclosed space was probably more favorable for eliciting responses from the infants. This is in agreement to the observation that lack of clutter and enclosed testing conditions is conducive to elicit better responses in individuals with special needs.^{23,24} While we could not map more meridians in the visual field isopter for some infants and children with developmental delay, we still were able to obtain quantifiable variable such as RT. This measure can be a useful outcome measure to monitor progress (or deterioration) of the visual condition in

these infants and children. Video recording and reviewing the data to quantify the RT (by any trained person) can eliminate examiner's bias and provide more reliable response.

We also acknowledge the limitations of our device and some subjectivity in the testing procedure. The repeatability (or intrasubject variability) and intersubject variability of the Pediatric perimeter was not investigated. Intrasubject variability on 6–7 month old infants is reported to be approximately 4° to 11° and intersubject variability to be approximately 10°.⁸ The VFE that was measured on infants with normal milestones showed a maximum VFE of 67°, 70°, and 62° in the superior, left, and right quadrants, respectively. These values are in agreement with those reported in the earlier literature.¹⁰ However, due to the construction constraint of the dome, the inferior visual field can be measured only up to 50°. This is a limitation because visual field loss beyond 50° may not be captured. Inferior visual field will be important to consider particularly for children with cortical visual impairment due to periventricular leucomalacia.²⁵ One way to overcome this limitation is to modify the algorithm to adaptively give a fixation light to relatively more superior LED and then compute the inferior visual field. We are presently working on such algorithms.

Of the four groups tested (Table 2), a trend of slower RT was observed in infants with developmental delay when compared with that of infants with normal milestones (Table 2). Children with developmental delay and patients with cognitive impairment had much slower RT than the infant group. These trends however would need to be more carefully examined using a larger sample size. There is also recent evidence from eye movement studies indicating a longer RT in children with cortical visual impairment (CVI).²⁶

The validation experiment in adults with simulated visual field loss showed the empirically mapped visual field radius was larger by 3° than the calculated visual field radius (16°). This difference could be due to measurement error and/or sampling limitation (3° LED separation) in the Pediatric Perimeter. In validating the visual field isopters obtained on Pediatric Perimeter and from the kinetic mode of HVF for three adult patients, an overestimate of the isopter by approximately 16° radius was found. This is rather a larger difference than what was found with the simulator goggles. The possible reasons for this difference in addition to measurement or sampling errors could be the different testing

conditions altogether between the two devices. The detection response in HVF is through a button press by the participant, whereas in the Pediatric Perimeter is by verbal response from the participant, which is then registered by the examiner. HVF testing is closer to photopic-mesopic condition where as in Pediatric Perimeter the testing is closer to mesopic-scotopic condition. It is known that visual performance in different lighting conditions can be different.²⁷ Under dark testing conditions, one can expect more sensitivity to the stimulus light, and therefore a larger visual field isopter. It is also possible that different neural mechanisms are tested under these two testing conditions. Moreover it is known that comparisons of visual fields between different instruments will be difficult for the reasons mentioned above. Upon investigating the intersection area, a closer match was obtained in the patient with glaucoma and the least match was found in the patient with hemianopia. It is unclear if an interaction is present between the disease condition and the testing conditions as well. The sample size of three patients is too small to speculate and this would warrant further investigation. While validation on adults may not necessarily be generalized to the infant population, lack of clinical devices to test infants poses a challenge to compare our device with another device.

Encouraging eye movements toward the stimuli instead of instructing the patient to hold a steady straight ahead fixation facilitated the testing in our patients. Such a perimetric procedure of permitting eye movements is increasingly explored both for adults and children.^{2,28} However, the testing conditions for those equipments require the patient to be seated. We found the supine position in dark room testing to be encouraging for our patients with cognitive impairment. It will be useful to further examine if better responses are elicited in the supine or sitting position for this group of patients with eye movement perimetry.

In conclusion, Pediatric Perimeter is a device that shows promise as a clinical device to map visual fields in infants and patients with special needs. Such testing would be valuable for infants, children, and adults having neurological conditions for diagnosing, managing, and monitoring the vision problems. Knowing the visual field status of these patients can also enhance the rehabilitation plans for these patients. The device can be easily adapted into pediatric, neurology, and ophthalmology clinics.

Acknowledgments

A Patent has been filed for this device. Patent Application No: 4341/CHE/2015 (PCT/IB2016/054148)

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References

- Patel DE, Cumberland PM, Walters BC, Russell-Eggitt I, Rahi JS; for the OPTIC study group. Study of Optimal Perimetric Testing in Children (OPTIC): feasibility, reliability and repeatability of perimetry in children. *PLoS One*. 2015;10:e0130895.
- Miranda MA, Henson DB, Fenerty C, Biswas S, Aslam T. Development of a pediatric visual field test. *Transl Vis Sci Technol*. 2016;5(6):13.
- Biagioni E, Cioni G, Cowan F, et al. Visual function and EEG reactivity in infants with perinatal brain lesions at 1 year. *Dev Med Child Neurol*. 2002;44:171–176.
- van Hof-van Duin J, Cioni G, Bertuccelli B, Fazzi B, Romano C, Boldrini A. Visual outcome at 5 years of newborn infants at risk of cerebral visual impairment. *Dev Med Child Neurol*. 1998;40:302–309.
- Satgunam P, Peli E. Torsional anomalous retinal correspondence effectively expands the visual field in hemianopia. *Optom Vis Sci*. 2012;89:E1353–E1363.
- Gamio S, Melek N. When the patient says no. Management of exotropia with hemianopic visual field defects. *Binocul Vis Strabismus Q*. 2003;18:167–170.
- Levy Y, Turetz J, Krakowski D, Hartmann B, Nemet P. Development of compensating exotropia with anomalous retinal correspondence after early infancy in congenital homonymous hemianopia. *J Pediatr Ophthalmol Strabismus*. 1995;32:236–238.
- Mayer DL, Fulton AB, Cummings MF. Visual fields of infants assessed with a new perimetric technique. *Invest Ophthalmol Vis Sci*. 1988;29:452–459.
- Delaney SM, Dobson V, Mohan KM. Measured visual field extent varies with peripheral stimulus flicker rate in very young children. *Optom Vis Sci*. 2005;82:800–806.
- Dobson V, Brown AM, Harvey EM, Narter DB. Visual field extent in children 3.5-30 months of age tested with a double-arc LED perimeter. *Vision Res*. 1998;38:2743–2760.
- Koenraads Y, Braun KP, van der Linden DC, Imhof SM, Porro GL. Perimetry in young and neurologically impaired children: the Behavioral Visual Field (BEFIE) Screening Test revisited. *JAMA Ophthalmol*. 2015;133:319–325.
- Mohn G, Van Hof-van Duin J. Behavioural and electrophysiological measures of visual functions in children with neurological disorders. *Behav Brain Res*. 1983;10:177–187.
- Allen LE, Slater ME, Proffitt RV, Querton E, Pelah A. A new perimeter using the preferential looking response to assess peripheral visual fields in young and developmentally delayed children. *J AAPOS*. 2012;16:261–265.
- Drum B. Hybrid perimetry: a blend of static and kinetic techniques. *Appl Opt*. 1987;26:1415–1420.
- Hart WM. Adler's Physiology of the Eye. St. Louis, MO: C. V. Mosby; 1992.
- Bieber ML, Volbrecht VJ, Werner JS. Spectral efficiency measured by heterochromatic flicker photometry is similar in human infants and adults. *Vision Res*. 1995;35:1385–1392.
- Duckman RH. Visual Development, Diagnosis, and Treatment of the Pediatric Patient. Philadelphia, PA: Lippincott Williams & Wilkins; 2006.
- Dobson V. Spectral sensitivity of the 2-month infant as measured by the visually evoked cortical potential. *Vision Res*. 1976;16:367–374.
- Teller DY, Pereverzeva M, Civan AL. Adult brightness vs. luminance as models of infant photometry: variability, biasability, and spectral characteristics for the two age groups favor the luminance model. *J Vis*. 2003;3(5):333–346.
- Wyszecki G, Stiles WS. Color Science. New York: Wiley; 1982.
- Delaney SM, Dobson V, Harvey EM, Mohan KM, Weidenbacher HJ, Leber NR. Stimulus motion increases measured visual field extent in children 3.5 to 30 months of age. *Optom Vis Sci*. 2000;77:82–89.

22. Nowomiejska K, Vonthein R, Paetzold J, Zagorski Z, Kardon R, Schiefer U. Comparison between semiautomated kinetic perimetry and conventional Goldmann manual kinetic perimetry in advanced visual field loss. *Ophthalmology*. 2005;112:1343–1354.
23. Little S, Dutton GN. Some children with multiple disabilities and cerebral visual impairment can engage when enclosed by a ‘tent’: is this due to Balint syndrome? *Br J Vis Impair*. 2015;33:66–73.
24. Dutton GN. Cerebral visual impairment: Working within and around the limitations of vision. In: Dennison E, Lueck AH, eds. *Proceedings of the Summit on Cerebral/Cortical Visual Impairment*. New York: AFB Press; 2005:3–26.
25. Jacobson LK, Dutton GN. Periventricular leukomalacia: an important cause of visual and ocular motility dysfunction in children. *Surv Ophthalmol*. 2000;45:1–13.
26. Kooiker MJ, Pel JJ, van der Steen-Kant SP, van der Steen J. A method to quantify visual information processing in children using eye tracking. *J Vis Exp*. 2016;9.
27. Barbur JL, Stockman A. Photopic, Mesopic and Scotopic Vision and Changes in Visual Performance. Oxford, UK: Elsevier; 2010.
28. Mazumdar D, Pel JJ, Panday M, et al. Comparison of saccadic reaction time between normal and glaucoma using an eye movement perimeter. *Indian J Ophthalmol*. 2014;62:55–59.