Circular Contrast Perimetry via Web Application

A Patient Appraisal and Comparison to Standard Automated Perimetry

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Purpose: The purpose of the study was to compare a novel, 24°, 52-locus online circular contrast perimetry (OCCP) application against standard automated perimetry (SAP) in terms of both diagnostic accuracy and patient attitudes.

Design: This was a cross-sectional study.

Subjects: Ninety-five participants (42 controls and 53 open-angle glaucoma patients) were included.

Methods: Participants performed both perimetry tests and then completed an online survey. Subjective feedback responses were collected.

Main Outcome Measures: Agreement, sensitivity, specificity, and area under receiver operating curves (AUCs) were compared for the parameters of OCCP, SAP, and OCT for the retinal nerve fiber layer (RNFL) and macular ganglion cell complex inner plexiform layer (GCC + IPL). Participant attitudes toward the OCCP test versus the SAP test, in both glaucoma patients and controls, were compared. Rasch analysis assessed the psychometric properties of the survey and intergroup variability.

Results: The AUC for OCCP mean deviation (MD) was 0.959 ± 0.02. Compared with other instruments' parameters with the highest AUC, it was superior to SAP MD (0.871 ± 0.04, $P = 0.03$) and OCT GCC + IPL (0.871 ± 0.04, $P = 0.03$) and similar to OCT RNFL inferior thickness (IT) (0.917 ± 0.03, no significance). Online circular contrast perimetry pointwise sensitivity was less than SAP by 4.30 dB (95% confidence interval = 4.02−4.59); 95% limits of agreement ranged from −6.28 to −2.33 dB. At the best cutoff, the OCCP MD had a sensitivity of 98% and specificity of 85% for detecting glaucoma. Cohen's kappa demonstrated good agreement with SAP MD (0.69) and OCT RNFL IT (0.62) and moderate agreement with OCT GCC + IPL IT (0.57). Participants preferred OCCP across most survey parameters ($P < 0.0001$). Rasch analysis demonstrated no differential item functioning for clinical group, gender, or age.

Conclusions: With similar diagnostic metrics to SAP, OCCP offers an improved user experience with the potential to increase the provision of care and improve disease surveillance outcomes. *Ophthalmology Science 2022;2:100172 © 2022 by the American Academy of Ophthalmology. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).*

Supplemental material available at www.ophthalmologyscience.org.

Glaucoma is among the world's leading causes of irreversible vision loss, requiring timely detection and lifelong clinical surveillance.[1,2] Perimetry is essential for detecting glaucomatous visual field changes and monitoring the progression of the disease, for which standard automated perimetry (SAP) is a commonly utilized modality.[3] Despite frequent use in clinical practice, office-based perimetry generates several logistical challenges including the requirement for precalibrated machines, high costs of installation and maintenance, appropriate training for office staff, and long patient waiting times.[4–7]

Developing low-cost, accessible glaucoma screening and monitoring tools that can be operated remotely is crucial for adapting to our aging population, the growing burden of chronic eye disease and limited health care resources.[8] Home-based perimetry applications that can be operated via the patient's electronic device offer a promising alternative to clinic-based assessment.[9] These technologies may help to increase early disease detection rates,[6] facilitate more frequent clinical monitoring, and provide greater access to care, particularly in resource-poor and remote communities. The importance of home-based health care has been

made clear throughout the COVID-19 pandemic, with community restrictions limiting access to many inpatient services.[10] A recent study evaluated online circular contrast perimetry (OCCP) via a novel web-based application and found favorable performance and diagnostic accuracy when compared with SAP and OCT parameters.[11] Another study of a normal cohort performing OCCP demonstrated consistent results sufficient to determine parameters for a normative data set.[12]

Ideally, the test's user experience must be intuitive, comfortable, and acceptable. Patients often report negative experiences following routine perimetry.[13] Anxiety, claustrophobia, and stress are often reported and are potential barriers to adherence to monitoring services.[14,15] Developing more user-friendly means of assessment perimetry would improve the patient experience and quality of life.

This study aimed to conduct a patient-based critical appraisal of the OCCP test compared with the SAP test, both performed under supervision in the clinic, to understand the patient experience for each visual field test. It also aimed to evaluate the OCCP as a diagnostic tool for glaucoma in comparison with the SAP.

Methods

Subjects

A cross-sectional study was performed on patients with open-angle glaucoma and healthy controls who were recruited from a sub-specialist ophthalmology practice in Melbourne in 2021. Patients were consecutively invited to participate in the study after providing written, informed consent. The study conformed to the tenets outlined in the Declaration of Helsinki. Ethical approval was obtained from the Human Research Ethics Committee of the Royal Australian and New Zealand College of Ophthalmologists (Human Research Ethics Committee reference number: 90.18).

Inclusion criteria were as follows: best-corrected visual acuity < 0.7 logarithm of the minimum angle of resolution, open anterior chamber angle, reliable SAP and OCCP test results, satisfactory OCT image quality, absence of ocular pathology other than glaucoma (such as visually significant cataract [Lens Opacities Classification System III greater than grade 2],[16] nonglaucomatous optic neuropathy, retinal or macular pathology), and willingness and ability to provide informed written consent.

Exclusion criteria included the following: unreliable or incomplete SAP and OCCP results, ametropia $>\pm5$ diopters, secondary causes of glaucoma, angle abnormalities, papillary anomalies, large peripapillary atrophy, neurological disorders, medication that could modify visual field results (i.e., chloroquine, vigabatrin, pilocarpine, etc.), previous intraocular surgery (excluding cataract surgery performed at least 6 months previously), and media opacities preventing good image scans.

Reliability criteria for SAP and OCCP tests included false-negative > 33%, false-positive > 15%, and fixation losses > 20%. A normal SAP result was determined according to Hodapp and associates' criteria.[17] Standard automated perimetry tests were defined as glaucomatous following the Anderson and Patella criteria.[18]

OCT scans with signal strength < 8 of 10 or with segmentation errors were rejected. All examinations were reviewed for appropriate centration by the ophthalmologist S.S. Normal optic nerve head (ONH) and retinal nerve fiber layer (RNFL) appearances were clinically defined as the absence of diffuse or focal rim thinning, cupping, localized pallor, optic disc hemorrhage, or RNFL defects and cup-to-disc ratio ≤ 0.7. The ONH and RNFL were classified as glaucomatous optic neuropathy if at least one of the following was evident: focal or diffuse atrophy of the neural rim area involving ≥ 2 clock hours, notching involving ≥ 2 clock hours, intereye vertical cup-to-disc asymmetry ≥ 0.3, ONH excavation, generalized or focal atrophy of the RNFL, or disc hemorrhage.

Participants were classified into 2 groups:

- Controls (normal ONH and RNFL appearance and SAP results and no family history of glaucoma and other ocular pathologies);
- Open-angle glaucoma (based on gonioscopy findings, characteristic disc appearance, and visual field changes defined on Anderson's criteria).[18]

Clinical Assessment

All participants underwent ophthalmic assessment including a thorough personal and family history to identify any systemic pathology that necessitated their exclusion from the study, Cirrus OCT of the ONH (Carl Zeiss Meditec Inc) and macula, central corneal thickness using the PachMate handheld pachymeter, intraocular pressure using the Goldmann applanation tonometer (Haag-Streit International), SAP with the Humphrey Field Analyzer Swedish Interactive Threshold Algorithm standard 24-2 test (Zeiss), and OCCP test. For both OCCP and SAP, participants were given sufficient instruction and explanation as to the process of visual field testing and were supervised by a trained, experienced orthoptist during the test to ensure clinically appropriate test results. For clinical and perimetric data, one eye was selected randomly per participant.

The OCCP Test

The OCCP test was delivered via a web-based application on clinic computers, using circular flickering targets to assess 52 loci over $24°$. These targets were similar to those used in pulsar perimetry (Haag-Streit International) with the same level of contrast in all radial directions to avoid stimulating cells that respond to a given orientation. However, our targets were slightly smaller in size ($3.5°$ vs. $5°$ of visual angle), and contrast was consistent throughout the target except for a slight reduction at the peripheral target rim. Like traditional frequency doubling perimetry (Welch Allyn, and Carl Zeiss Meditec), targets appeared for 60 milliseconds for 3 on/off cycles, totaling 360 milliseconds. The contrast was ramped up and down at the beginning and ends of target presentations to prevent temporal transients.[19,20] Targets alternated between concentric light and dark bands. Unlike frequency doubling perimetry, where both light- and dark-band target contrasts vary around a mean background of luminance, light-band targets were presented on a fixed background color (light gray); dark-band targets varied to achieve the desired contrast level. This is similar to a luminance pedestal flicker for stimulus decrements, as described by Anderson and Vingrys.[21]

Relative luminance (as a percentage) ranged from pure white (255,255,255) as 100% and black (0,0,0) as 0% and was calculated for each 256-bit grayscale level defined based on the Web Content Accessibility Guidelines standards for relative luminance calculation.[22] Target contrast (in relative decibels) was calculated using the Michaelson formula by comparing peaks and troughs of targets:[23]

$$\text{Relative decibel(rdB)} = -2\log(RL_1 - RL_2) / (RL_1 + RL_2),$$

where RL_1 is the light band maximum and RL_2 is the dark band minimum relative luminance.

Participants requiring spectacles for near-viewing were instructed to wear them for the test. Participants were required to maintain their gaze on a fixation point (a spinning golden star) and

Table 1. Participant Survey Questions for the Online Circular Contrast Perimetry versus Standard Automated Perimetry Tests

Number	Question
1	I found the overall experience to be enjoyable
2	I was able to maintain concentration during the test
3	The level of feedback provided was helpful
4	It was clear what was expected of me during the test
5	I found the clicker easy to use
6	It was easy to keep my gaze focused on the central target
7	I found the test too long
8	I was uncomfortable in my posture
9	I felt the test was stressful
10	I found the verbal guidance during the test irritating
Q1	Did you prefer the conventional (machine-based) or the online (computer-based) visual field test?
Q2	How much do you value being able to do an online visual field test remotely?
Q3	I am bothered by the webcam monitoring my face during the online test (I understand the video is not saved and no facial recognition occurs)

Questions 1 to 10 were repeated for each test.

then click the mouse when they saw a target appear in their peripheral vision. The sequence of target presentations was influenced by the user's response time in addition to random delays between target presentations to prevent rhythmic responses. Verbal guidance and sound guidance were used to navigate the participant through the test. All voice prompts were provided in English. When users clicked correctly, a positive, reassuring sound was elicited (similar to finding a coin on a computer game). Incorrect clicks produced a negative sound (similar to the error sounds produced in computer games)—this was noted as a false-positive.

The participant's head position was monitored using facial detection with artificial intelligence via the computer screen's webcam. Correct viewing distance was determined by the size of the monitor, with guidance from both webcam monitoring and blind spot localization. The blind spot area was estimated at 15° temporal and 0.5° inferior. A grid spanning 4 × 10° overlaid the blind spot areas; spots nearby were assessed by OCCP to map out the user's blind spot. Simple trigonometry was then used to space the blind spot and loci on the monitor relative to fixation; users completed OCCP at a viewing distance of 40 to 45 cm. Indices of reliability were assessed similarly to SAP. Fixation losses were assessed using smaller stimuli presented within the measured blind spot at 0 dB, false-positives were measured as the number of inappropriate mouse clicks during latency periods, and false-negatives were assessed with stimuli brighter than measured sensitivity (Se).

The OCCP was coded in JavaScript, whereas the server-side web application was coded using a Python microframework. The window.request Animation Frame object with a timestamp callback in the JavaScript code allows for the precision of timing measurements for locus presentations, despite potential inconsistencies in the screen refresh rate.

Test Settings. The OCCP test has an inbuilt mechanism for guiding the user through a pretest screen calibration to ensure consistency of testing metrics. However, for this scientific study, calibration was performed using a SpyderX screen photometer (Datacolor). Background screen luminance was set at relative luminance with 224 cd/m^2 output. Gamma was set at 2.2, and white temperature was set at 6500K, consistent with most modern monitor displays, and all monitors used were 24-inch diagonal

screen size with a resolution of 1920 × 1080 pixels. Participants performed the OCCP test within a controlled environment. Background lighting and sound were standardized. The room lighting conditions were kept dark (save for the monitor light), and the computer was turned on for at least 30 minutes before test administration to ensure consistency of adaptation and screen brightness.

A trained test administrator (L.B.) ensured strict participant adherence to testing protocol, providing initial instruction and guidance to the participant immediately before the commencement of testing, followed by supervision during the test. Participants completed the online test for each eye separately. Participants were then offered the feedback survey immediately after test completion.

Feedback Survey

The survey, based on a similar study exploring comparative experiences during perimetry,[14] was designed by the chief investigator to capture the differences in experience between the SAP and OCCP tests. It contained 2 sets of 10 identical questions, each set for the SAP and OCCP experience (Table 1). Three additional questions were related to the participant's preference for either test, their opinion of remote perimetry, and their opinion about the OCCP test's webcam facial monitoring. An optional textbox for further comments was provided. Responses were recorded in a Likert scale: "strongly disagree," "disagree," "neutral," "agree," or "strongly agree," corresponding from 1 to 5. Participants completed the survey anonymously. All data were stored securely on a password-protected database. Only investigators J.M., Y.D., L.B., and S.S. had access to this database.

Main Outcome Measures

Agreement, Se, specificity (Sp), and area under receiver operating curves (AUCs) were compared for the parameters of OCCP, SAP, and OCT for the RNFL and macular ganglion cell complex inner plexiform layer (GCC + IPL). Participant attitudes toward the OCCP test versus the SAP test, in both glaucoma and control groups, were compared.

Statistical Analysis

Statistical analyses were conducted using Statistical Package for Social Sciences (SPSS, Inc) and Real Statistics in Excel 2016 (Microsoft 365). Significance was set at $P < 0.05$, with adjustment by the Bonferroni method. Data were checked for normality using the Shapiro–Wilk statistic. Intergroup differences were assessed using the nonparametric Mann–Whitney U analysis of ranks and Student t test for parametric data. Bland–Altman analyses were used to analyze the agreement and estimate the 95% limits of agreement between the 2 tests' mean deviation (MD), pattern standard deviation, and mean Se per eye and per point. Differences in survey item responses were compared using the paired t test for parametric data. The ordering of Likert scale responses was reversed for negative questions 7 to 10 for consistency of comparative analysis.

We calculated the best cutoff point (defined as the value dividing healthy from glaucomatous eyes with the highest probability, maximizing Se + Sp), Se at 80% and 90% Sp and AUC for detecting glaucoma for all considered parameters of the OCCP, SAP, and OCT of the RNFL and GCC + IPL. The highest AUC in diagnosing glaucoma corresponding to the parameter from each of OCCP, SAP, and OCT of the RNFL and GCC + IPL was then compared. The chi-square test was used to calculate differences among sensitivities and specificities; differences among the AUCs were evaluated using the Hanley–McNeil method.[24] Cohen's

Table 2. Patient Characteristics and Perimetric Test Results: Glaucoma versus Control Groups

Variables	Control Group	Glaucoma Group	P Value
Gender (F/M)	17/25	25/28	NS
Disease severity: number (%)			
Mild	-	31 (58.5)	-
Moderate	-	9 (17.0)	-
Severe	-	13 (24.5)	-
Abnormal ONH (% eyes)	0	100	-
Age (year), median, interquartile range	65, 53–73	72, 63–79	NS
logMAR visual acuity	−0.00 ± 0.08	0.10 ± 0.15	<0.0001
Corrected IOP (mmHg)	15.76 ± 3.62	12.66 ± 4.11	0.0009
CCT (μm)	565.74 ± 38.58	542.51 ± 40.40	0.0023
Spherical equivalent (D)	0.18 ± 2.30	−0.43 ± 2.48	NS

Instrument	Parameter	Control Group	Control Group	P Value
OCCP	MD (dB)	0.81 ± 1.18	−6.91 ± 5.60	<0.0001
	PSD (dB)	2.32 ± 0.65	5.02 ± 2.41	<0.0001
	VFI (%)	98.67 ± 1.39	80.28 ± 18.28	<0.0001
	Duration (minutes:seconds)	3:21 ± 0:33	4:59 ± 1:05	<0.0001
SAP	MD (dB)	−0.40 ± 1.64	−7.16 ± 7.47	<0.0001
	PSD (dB)	1.92 ± 1.53	5.64 ± 4.05	<0.0001
	VFI (%)	98.55 ± 3.44	81.17 ± 23.37	<0.0001
	Duration (minutes:seconds)	4:58 ± 0:44	6:09 ± 1:06	<0.0001
OCT RNFL	Mean thickness (μm)	90.74 ± 8.93	69.87 ± 14.48	<0.0001
	Superior thickness (μm)	112.02 ± 14.36	81.47 ± 19.68	<0.0001
	Inferior thickness (μm)	117.24 ± 17.21	78.28 ± 24.18	<0.0001
	VCDR	0.47 ± 0.19	0.71 ± 0.16	<0.0001
OCT GCC + IPL	Average thickness (μm)	77.98 ± 6.85	65.15 ± 9.77	<0.0001
	Superior thickness (μm)	78.16 ± 6.90	66.75 ± 11.44	<0.0001
	Inferior thickness (μm)	77.89 ± 7.11	63.43 ± 10.09	<0.0001

CCT = central corneal thickness; D = diopters; GCC = ganglion cell complex; IOP = intraocular pressure; IPL = inner plexiform layer; logMAR = logarithm of the minimal angle of resolution; MD = mean deviation; NS = not significant; OCCP = online circular contrast perimetry; ONH = optic nerve head; PSD = pattern standard deviation; RNFL = retinal nerve fiber layer; SAP = standard automated perimetry; VCDR = vertical cup-to-disc ratio; VFI = visual field index.

Values given are mean ± standard deviation unless otherwise specified. Glaucomatous eyes were subdivided by SAP MD deficit into mild (MD >−6.0 dB), moderate (MD −12.0 to −6.0 dB), and severe (MD <−12.0 dB) groups.

kappa was utilized to assess agreement among the best parameters of each instrument at the best cutoff.[25] Levels of agreement with the kappa statistic were defined as follows: excellent (> 0.81), good (0.61–0.80), moderate (0.41–0.60), fair (0.21–0.40), and poor (< 0.20).

Rasch Analysis

Rasch analysis was used to assess the psychometric properties of the administered survey using the Andrich rating scale model with Winsteps software.[26–28] Differential item functioning was used to assess differences in responses based on gender, clinical group (controls vs. glaucoma), and age stratification: younger (age < 65 years) and older (age ≥ 65 years).

Results

The cohort consisted of 95 participants, of whom 42 were controls and 53 had glaucoma. Eight individuals did not complete the survey: 1 because of cognitive impairment, 3 because of language difficulties, and 4 because of lack of time. These participants were excluded from the Rasch analysis of survey data, but their clinical and perimetry data were included. The cohort's clinical and perimetric

characteristics are provided in Table 2. The mean age was 66.3 (± 14.5) years, of which 60 (63.2%) participants were at least 65 years old. Of the participants with glaucoma, 31 had mild (SAP MD > −6 dB), 9 had moderate (SAP MD −6 to −12 dB), and 13 had severe (SAP MD < −12 dB) glaucoma. Online circular contrast perimetry mean testing duration was lower than SAP in both the control (3:21 ± 0:33 vs. 4:58 ± 0:44, P < 0.0001) and glaucoma (4:59 ± 1:05 vs. 6:09 ± 1:06, P < 0.0001) groups.

Rasch Analysis

The survey results displayed a good fit to the Rasch model, with no evidence of multidimensionality or disordered thresholds. Person separation and person reliability indices were acceptable on initial analysis (2.03 and 0.8, respectively); however, targeting was suboptimal (1.83, ideal = −1 to 1). Item misfit was detected for item Q2—on a subsequent iteration, this was removed, which resulted in a deterioration of targeting to 2.16. For this reason, all items were included in the final Rasch model. No differential item functioning was detected for clinical group, gender, or age,
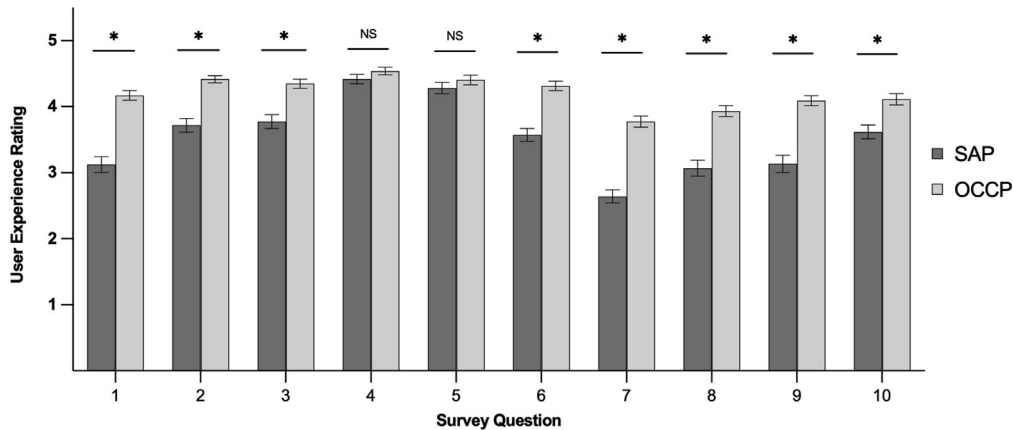
Figure 1. Pairwise comparison of user experience ratings for online circular contrast perimetry (OCCP) versus standard automated perimetry (SAP) from survey questions 1 through 10. Boxes represent the mean rating score, and whisker bars represent standard error. *$P < 0.0001$.

indicating the survey responses were consistent for these groups.

Participants' attitudes toward SAP versus OCCP are outlined in Figure 1. The OCCP test outperformed the SAP test on most survey items ($P < 0.0001$) apart from items 4 (the clarity of the tests' expectations) and 5 (the ease of using the mouse clicker), for which no significant difference was detected. Figure 2A displays the relative frequencies of participants' visual field test preferences, showing a stronger preference for the OCCP test (84.3% vs. 2.2%; 13.5% displayed no preference). Figure 2B shows the relative frequencies of participants' overall attitudes toward the option of remote perimetry; this was valued by most (71.9%) participants. Figure 2C overviews the participants' potential concerns regarding the OCCP test's webcam monitoring of their face; only 3.4% of the cohort were bothered by this.

Twenty-four participants provided qualitative feedback (Table S1, available at https://www.ophthalmologyscience. org). Several participants (P2, P10, P28, P45, P51, P56, P68, P69, P71, P83, and P89) reported that the OCCP test had advantages over SAP, including being more comfortable and convenient and less stressful and invasive. Some participants found it particularly difficult to focus on the spinning fixation point (P28, P34, P49, and P78). Other participants (P14, P15, and P28) found the sound effects and verbal guidance disruptive. There were also queries raised over the availability of test results and their accuracy (P14 and P83).

Figure 3 presents Bland−Altman plots comparing OCCP to SAP. Online circular contrast perimetry pointwise Se was less than SAP by 4.30 dB (95% confidence interval = −4.59 to −4.02); 95% limits of agreement ranged from −6.28 to −2.33 dB. Table 3 displays the best cutoff values, Se, Sp, and AUC for glaucoma diagnosis for all considered parameters. The following parameters demonstrated the greatest AUC in distinguishing between glaucomatous and nonglaucomatous eyes: MD for SAP, MD for OCCP, RNFL inferior thickness (IT), and GCC + IPL IT, shown in Figure 4. Significance for

comparison between these AUCs and levels of agreement using Cohen's kappa for these parameters are shown in Table 4. The OCCP test showed a high performance in discriminating glaucomatous eyes from nonglaucomatous eyes based on the MD (Se of 98% and Sp of 85% at the best cutoff), with AUC (0.959 ± 0.02) higher than SAP MD (0.871 ± 0.04, $P = 0.03$) and OCT GCC + ICL (0.871 ± 0.04, $P = 0.03$) and similar to OCT RNFL IT (0.917 ± 0.03, no significance). Agreement with other instruments' best parameters on Cohen's kappa was good with the SAP MD (0.69) and OCT RNFL IT (0.62) and moderate with OCT GCC + IPL IT (0.57).

Discussion

This cohort of glaucoma patients and controls found OCCP more enjoyable, more comfortable, and less stressful than SAP, consistent across age, gender, and clinical groups. Participants found it easier to maintain their concentration, found the feedback provided was more helpful, and felt overall, that the OCCP test was preferable to SAP. Analyses of AUCs demonstrate that the OCCP test differentiates glaucomatous from healthy eyes with strong AUC features and good or moderate agreement with SAP and OCT of the ONH parameters.

As an online test delivered through the web browser of personal computers, the OCCP test has the potential to expand and streamline the delivery of outpatient glaucoma screening and surveillance programs.[9,10] This will generate cost- and time-saving benefits for both patients and providers, including fewer clinic visits, improved access to care, and a lower health care burden.[10,29]

The key challenge was designing the OCCP as an intuitive, acceptable test that could be operated by a diverse spectrum of patients. In response to our aging population, this is particularly pertinent for older patients, given that advanced age, comorbidities, and disability can cause increased difficulties with navigating a digital interface, maintaining the correct posture, or staying focused.[15,30]
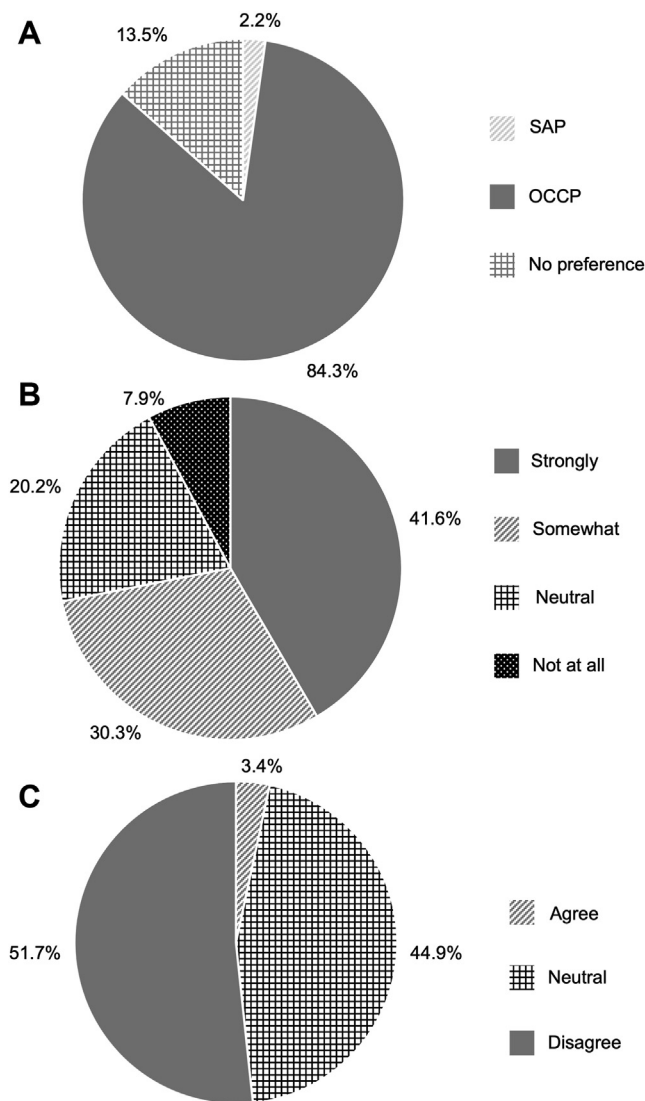
Figure 2. Survey response questions Q1 through 3. **A**, "Did you prefer the conventional (machine-based) or the online (computer-based) visual field test?" **B**, "How much do you value being able to do an online visual field test remotely?" **C**, "I am bothered by the webcam monitoring my face during the online test (I understand the video is not saved and no facial recognition occurs)." Relative frequencies are shown as percentages. OCCP = online circular contrast perimetry; SAP = standard automated perimetry.

However, our findings showed no age-related discrepancies in levels of discomfort or concentration, and > 50% of our participants were over the age of 65 years. This is a promising indicator that our application can be successfully delivered to older populations, improving their access to care.

An added challenge is optimizing the home environment to maintain the integrity of testing conditions. Our participants were assessed in a controlled, clinical environment under supervision by a trained research supervisor. This might be more difficult to replicate at home, and additional distractions from background noises, suboptimal lighting, or other household members may further compromise the

reliability of test indices.[10] Conversely, the home environment might be less stressful, and perhaps some users would perform testing better in a home environment. More work is required to assess the feasibility of the OCCP test for at-home monitoring, potentially using patients' personal computers. It is important to provide clear instructional content immediately before the test to ensure correct testing procedures and environmental setup at home. Possible solutions for distractions or concentration lapses have included incorporating artificial intelligence technology to detect small lapses in patient concentration[10] or supplying a viewing hood and supportive chin rest to best replicate the clinic-based testing conditions.[29] Our test uses many features to minimize the need for additional hardware, such as artificial intelligence to monitor facial positioning. As extra hardware represents a potential barrier to the scalability and usability of online perimetric testing, the strength of the OCCP test is that it only requires a personal device and a stable internet connection.

The OCCP test has been designed to work on both desktop and laptop computers of varying size screens, with inbuilt mechanisms to ensure the appropriate visual angle is assessed and the head position is correct and with a system for guiding the user through pretest screen calibration to ensure contrast is consistent across different screens. Perimetry has also been operated on other devices, including tablets, laptops, and virtual reality headsets.[6,9,31−38] Persitat perimetry, another computer-based software, showed similar performance indices to OCCP.[35] VirtualEye, a head-mounted, eye-tracking perimetry application using virtual reality goggles, showed reliable detection of large visual field deficits with good patient acceptability.[33] However, false-positives/negatives were common, in addition to issues with fixation losses.[33] Tablet-based perimetry offers an intuitive interface, with high diagnostic accuracy and reliable test−retest consistency, although there are limitations with gaze tracking and spatial−temporal precision.[6,9,32] Further studies are required to assess the consistency of OCCP testing across different monitor types that have received self-guided, pretest calibration—this should be easy to follow with clear instructions. More studies are also required to assess test−retest consistency and the feasibility of the OCCP test on other device types (such as tablets).

Optimizing the OCCP test's user experience is a crucial priority for promoting patient engagement and long-term adherence. Although integral to care, perimetry testing is commonly viewed by patients as the most stressful and difficult component of the consultation.[14,30] Patient anxiety can adversely affect both test performance and engagement.[15,16] Our data indicate that improvements to the user interface, test feedback, and patient comfort might contribute to a less stressful experience. Other factors that have been implicated include waiting room numbers, supportive staff availability, and clinic waiting times,[39] some of which can be effectively addressed through the capacity to undertake the OCCP test at home.

The additional autonomy and flexibility also encourage patients to take more of an active role in their care and monitoring. There are promising data on long-term patient compliance to home monitoring with a similar tablet-based
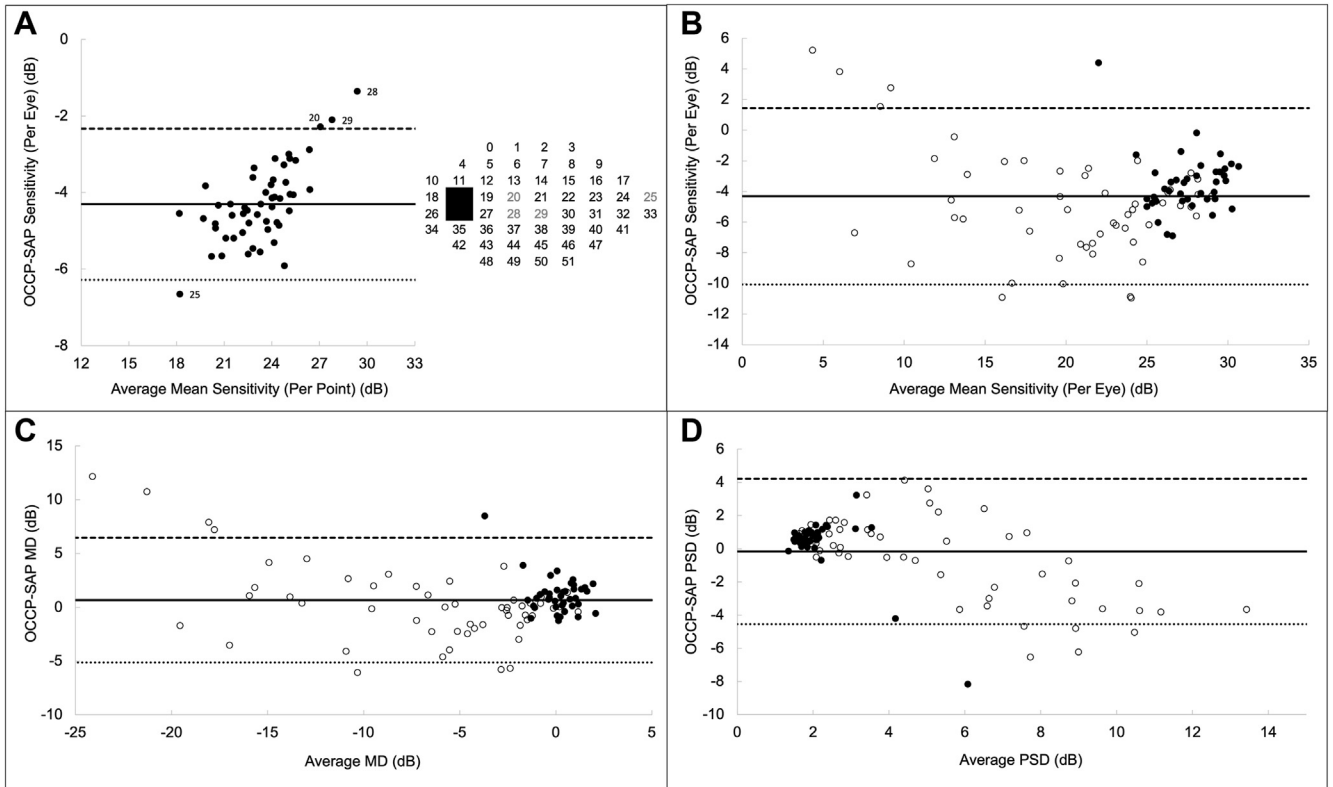
Figure 3. Bland−Altman plots. **A**, Mean sensitivity (per point) with outliers shown in gray on the visual field locus map (inset). **B**, Mean sensitivity (per eye). **C**, Mean deviation (MD). **D**, Pattern standard deviation (PSD). The continuous line represents the mean differences (bias) between the 2 tests. The dashed and dotted lines represent the 95% limits of agreement (bias ± 1.96 SD). Black colored circles represent controls, and white circles represent the glaucoma group. OCCP = online circular contrast perimetry; SAP = standard automated perimetry; SD = standard deviation.

perimetry application.[9] Particularly for higher-risk patients requiring closer clinical monitoring, the OCCP test can offer opportunities for more frequent clinical assessments,

enabling earlier detection of disease progression. Nevertheless, offering the OCCP test as part of routine monitoring should involve a thorough assessment of the individual's

Table 3. Area Under the Receiver Operating Characteristic Curve, Best Cutoff, Sensitivity, and Specificity for Discriminating between Glaucomatous and Control Eyes

Instrument	Parameter	AUC (SE)	P Value	Best Cutoff	Se/Sp at Best Cutoff (%)	Se at 80% Sp (%)	Se at 90% Sp (%)
OCCP	**MD (rdB)**	**0.959 (0.02)**	**<0.001**	**−1.61**	**98/85**	**100**	**90**
	PSD (rdB)	0.882 (0.03)	<0.001	2.55	81/85	83	57
	Mean threshold/eye	0.912 (0.03)	<0.001	22.04	100/79	79	57
SAP	**MD (dB)**	**0.871 (0.04)**	**<0.001**	**−1.8**	**95/74**	**76**	**43**
	PSD (dB)	0.867 (0.04)	<0.001	1.93	86/81	86	69
	Mean threshold/eye	0.852 (0.04)	<0.001	26.87	95/72	67	50
OCT RNFL	Mean thickness (μm)	0.899 (0.03)	<0.001	80	95/77	86	60
	Superior Thickness (μm)	0.887 (0.03)	<0.001	88	98/70	79	64
	Inferior thickness (μm)	**0.917 (0.03)**	**<0.001**	**100**	**86/85**	**86**	**76**
	VCDR	0.868 (0.04)	<0.001	0.59	71/92	76	71
OCT GCC + IPL	Average thickness (μm)	0.825 (0.04)	<0.001	69	98/60	58	50
	Superior thickness (μm)	0.784 (0.5)	<0.001	67.4	95/53	57	33
	Inferior thickness (μm)	**0.871 (0.04)**	**<0.001**	**69.1**	**93/68**	**76**	**55**

AUC = area under the receiver operating characteristic curve; GCC = ganglion cell complex; IPL = inner plexiform layer; MD = mean deviation; OCCP = online circular contrast perimetry; PSD = pattern standard deviation; rdB = relative decibel; RNFL = retinal nerve fiber layer; SAP = standard automated perimetry; Se = sensitivity; SE = standard error; Sp = specificity; VCDR = vertical cup-to-disc ratio.
The highest area under the receiver operating characteristic curve per device is shown in bold.
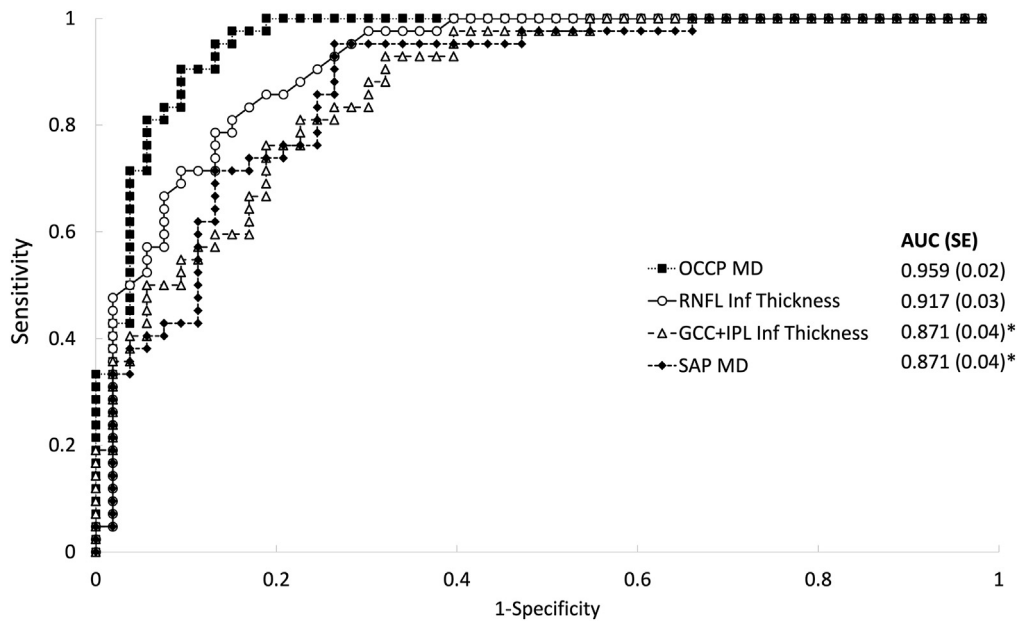
Figure 4. Areas under the receiver operator characteristics curves (AUCs). GCC = ganglion cell complex; IPL = inner plexiform layer; MD = mean deviation; OCCP = online circular contrast perimetry; RNFL = retinal nerve fiber layer; SAP = standard automated perimetry; SE = standard error. *Parameter AUC inferior to OCCP MD AUC, $P = 0.03$.

motivation with early identification of barriers to care on a case-by-case basis.

Bland–Altman analysis revealed a bias of 4.30 dB between SAP and OCCP mean sensitivities. This bias is similar to the bias found in our other studies and may indicate that the normal range for the OCCP physiological hill of vision is slightly lower than that for SAP.[11,12] This bias seems to be decreased for more central points (Fig 3A). Despite this, having more precisely determined this bias across a large normative database, there are reasonable data to suggest that OCCP is similarly sensitive to localized deviations in this hill as the hallmark of glaucoma detection, which is evidenced by its strong AUC indices and high agreement with SAP parameters. Notably, of the glaucoma participants, most had mild disease, whereas comparatively fewer had moderate and severe disease. Establishing whether OCCP can distinguish mild disease from normal eyes with similar accuracy to moderate and severe glaucoma would be a valuable insight, particularly for determining OCCP's disease screening potential. This is assessed in a larger validation study,[11] although the high AUC values observed in this current study support OCCP's good diagnostic accuracy across the spectrum of disease severities. Finally, a few patients with severe glaucomatous disease performed better in OCCP than in SAP, with higher values for the MD and mean Se per eye. This is possibly a combination of the small systematic bias between OCCP and SAP with a potential floor effect in very severe disease.

Table 4. Statistical Comparison of Percentage of Sensitivity, Specificity, Area Under Receiver Operating Characteristic Curve, and Kappa Statistic for Discriminating between Glaucoma and Control Eyes of the Best Parameter of Each Instrument

Parameter	Se (%) at Best Cutoff (P^c)	Sp (%) at Best Cutoff (P^c)	Se at 80% Sp (P^c)	Se at 90% Sp (P^c)	AUC Mean ± SE	P^h	Kappa Statistic at Best Cutoff
OCCP MD vs. SAP MD	NS	NS	<0.0001	<0.0001	0.088 ± 0.04	0.03	0.69
OCCP MD vs. OCT RNFL inferior thickness	0.007	NS	0.004	0.03	0.042 ± 0.04	NS	0.62
OCCP MD vs. OCT GCC + IPL inferior thickness	NS	0.02	<0.0001	<0.0001	0.088 ± 0.04	0.03	0.57
SAP MD vs. OCT GCC + IPL inferior thickness	NS	NS	NS	NS	0.00 ± 0.05	NS	0.70
OCT RNFL inferior thickness vs. GCC + IPL inferior thickness	NS	0.02	NS	0.007	0.046 ± 0.05	NS	0.65
SAP MD vs. OCT RNFL inferior thickness	NS	NS	NS	<0.0001	0.046 ± 0.05	NS	0.73

AUC = area under receiver operating characteristic curve; GCC = ganglion cell complex; IPL = inner plexiform layer; MD = mean deviation; NS = not significant; OCCP = online circular contrast perimetry; P^c = P calculated with the chi-square test; P^h = P calculated with the Hanley–McNeil method; RNFL = retinal nerve fiber layer; SAP = standard automated perimetry; Se = sensitivity; SE = standard error; Sp = specificity.

Our study has several limitations. Firstly, all data were based on participants from a single, multisite medical practice, which introduces the possibility of selection bias. This should be addressed in future, multipractice studies to best account for the diversity of patient populations. All participants completed the OCCP test after the SAP test, and this nonrandom order may have led to recall bias and learning effect, which may have strengthened OCCP test performance. Online circular contrast perimetry's improved user experience rating may also contribute to better performance as users feel more comfortable with the interface. This was to minimize disturbing the clinic flow for the medical practice. The survey also focused primarily on the user experience. Including broader standardized questions such as access to a personal device, the perceived value of out-of-pocket costs, concerns over data security, and adherence barriers would provide valuable insight into patient attitudes toward these relevant logistical factors. Finally, in this study, we did not assess the influence on patient cognition, comorbidity, and other quality-of-life indices that might have influenced test opinions. More studies are required to determine which sorts of patients are more suitable for online perimetry monitoring.

In conclusion, when performed in the clinic, the OCCP test offers a positive user experience, with similar diagnostic accuracy to SAP. The user feedback can be incorporated in future test design optimization for all forms of perimetry. The OCCP test may hopefully assist providers to meet the growing health demands of chronic eye disease and increase patient access to high-quality care.

Footnotes and Disclosures

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Disclosure(s):

All authors have completed and submitted the ICMJE disclosures form. A/Prof Simon Skalicky is the director of Eyeonic Pty Ltd which owns patent WO2021051162A1 regarding circular contrast perimetry.

HUMAN SUBJECTS: Human subjects were included in this study. Informed Consent was obtained from all participants. The study conformed to the tenets outlined in the Declaration of Helsinki. Ethical approval was obtained from the Human Research Ethics Committee of the Royal Australian and New Zealand College of Ophthalmologists (Human Research Ethics Committee reference number: 90.18).

No animal subjects were used in this study.

Author Contributions:

Research design: Meyerov, Deng, Busija, Skalicky

Data acquisition and/or research execution: Meyerov, Deng, Busija, Skalicky

Data analysis and/or interpretation: Meyerov, Deng, Busija, Skalicky
Obtained funding: N/A

Manuscript preparation: Meyerov, Deng, Busija, Skalicky

Abbreviations and Acronyms:
AUC = area under receiver operating curve; **GCC** = ganglion cell complex; **IPL** = inner plexiform layer; **IT** = inferior thickness; **MD** = mean deviation; **OCCP** = online circular contrast perimetry; **ONH** = optic nerve head; **RNFL** = retinal nerve fiber layer; **SAP** = standard automated perimetry; **Se** = sensitivity; **Sp** = specificity.

Keywords:
Glaucoma, Perimetry, Visual field test.

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