Performance of VisuALL virtual reality visual field testing in healthy children

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BACKGROUND Virtual reality field testing may provide an alternative to standard automated perimetry. This study evaluates a virtual reality game-based automated perimetry in a healthy pediatric population.

METHODS A prospective series of pediatric patients at one institution who performed VisuALL perimetry (Olleyes Inc, Summit, NJ) using a game-based algorithm. Participants were examined by an experienced pediatric optometrist or ophthalmologist, who confirmed that there was no evidence of ocular disease expected to affect visual fields. Testing was performed binocularly, with the child wearing their spectacle correction in place. Age, refractive error, test duration, false positives, and stereoacuity were evaluated for associations with performance on VisuALL, as defined by mean deviation (MD) and pattern standard deviation (PSD).

RESULTS A total of 191 eyes of 97 patients (54% female) were included, with a mean age of 11.9 ± 3.1 years. The average MD was -1.82 ± 3.5 dB, with a mean foveal sensitivity of 32.0 ± 4.7 dB. Fifty-nine eyes (30.9%) had MD < -2 dB. Better performance, as assessed by MD and PSD, was associated with shorter test duration ($P < 0.001$) and older age ($P < 0.001$). False positives ($P = 0.442$), wearing spectacles ($P = 0.092$), Titmus stereoacuity ($P = 0.197$), and refractive error ($P = 0.120$) did not appear to be associated with improved performance, adjusting for age as a covariate.

CONCLUSIONS VisuALL virtual reality field testing was well tolerated in this pediatric study cohort. Older age and shorter test duration were associated with better performance on field testing. (J AAPOS 2024;28:103802)

Visual field testing is a critical tool for evaluating patients in ophthalmology, especially those with glaucoma and neuro-ophthalmic problems.[1,2] The current standard of care for visual field testing is tabletop automated perimetry, such as the in-office Humphrey visual field (HVF) test (Zeiss Meditech, Dublin, CA). Goldmann kinetic perimetry is frequently used in younger children. While providing critical clinical information, HVF can be challenging to perform even for some adult patients.[3,4] Pediatric patients often struggle with remaining focused and engaged during automated perimetry, especially those patients <8 years of age.[5] In addition, the HVF test is built for mobile adults and is not accessible to some patients with disabilities or to those who have difficulty positioning and maintaining position in the machine.[6]

Virtual reality (VR) technology has increasingly provided users with a rich, immersive, and interactive experience. In addition, it has been explored as a potential tool in medical settings, including within ophthalmology.[7-11] VR is especially promising in children, where it can offer a more engaging and interactive way of recording field tests.[6]

VisuALL (Olleyes Inc, Summit, NJ), a portable VR-based field test, has been described as comparable to conventional HVF testing in examination of adults[8,11] and children.[6] It can perform a standard field test, with a format similar to the HVF 24-2 "SITA-Fast" testing algorithm, but the device also offers a video game–like format for visual field assessment intended to appeal to the pediatric population. The current study aimed to characterize the performance of the VisuALL game-based field test, termed the Pediatric 24-2 AVA standard visual field, in a healthy pediatric cohort.

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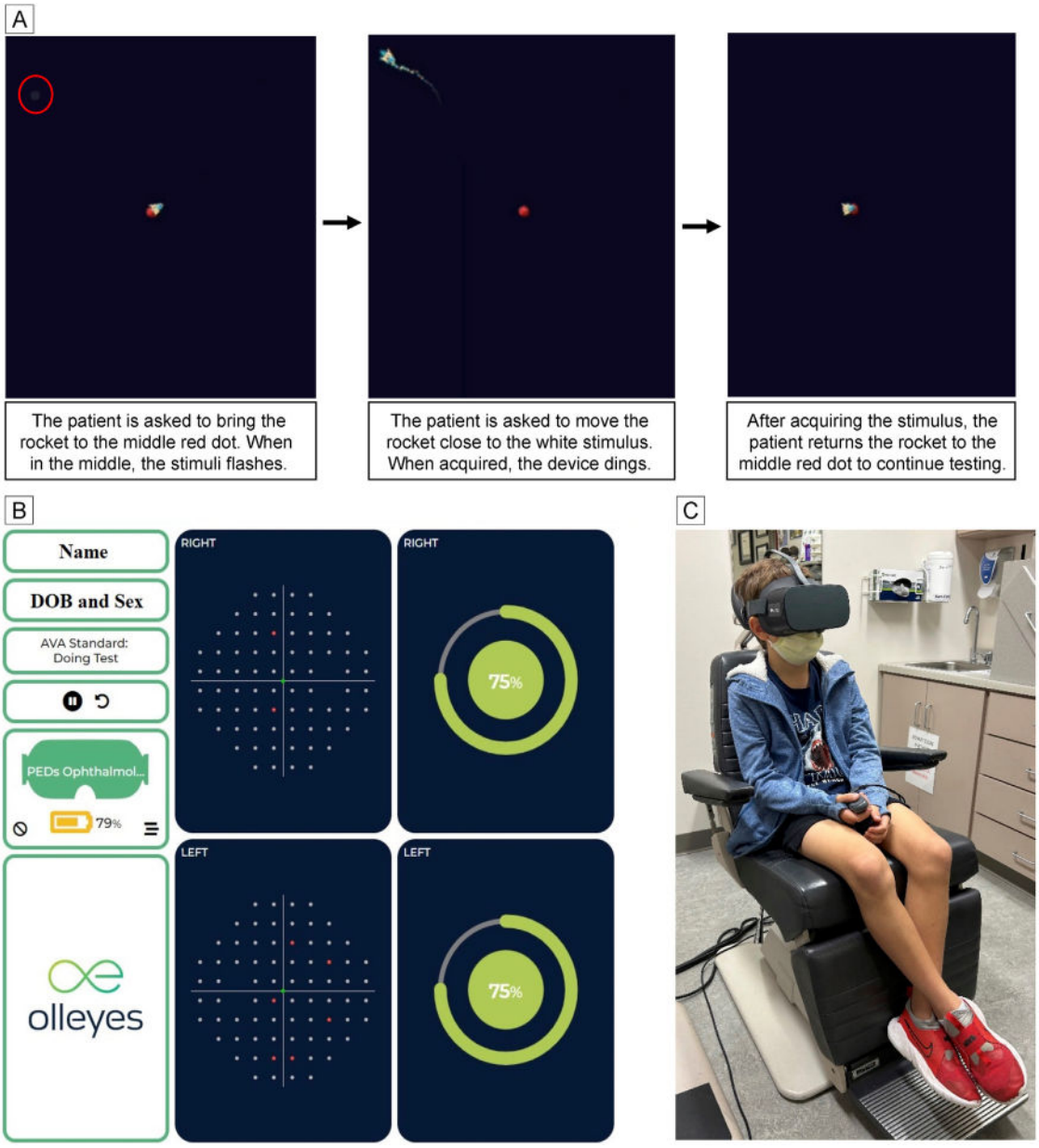

FIG 1. A, General testing paradigm for the virtual reality visual field. The patient moves the rocket to "Mars" (red dot), and a white stimulus (red circle) is shown. After moving the rocket to the stimulus, the headset dings, and the patient is asked to return the stimulus to the central red dot to continue testing. B, Tester view at 75% completion, showing the current field in the middle (white dots indicate captured stimulus; red dot, missed stimulus) and the percent of test completion to the right for each eye. C, Patient being fitted with the device before testing begins.

Subjects and Methods

This prospective study was approved by the Duke Institutional Review Board and was conducted in accordance with the US Health Insurance Portability and Accountability Act of 1996.

Healthy patients <18 years of age presenting to the Duke Eye Center for a visit with a pediatric optometrist or pediatric ophthalmologist were enrolled. The enrollment period lasted from January 2022 through December 2022. Inclusion criteria included the following: (1) corrected visual acuity of 20/40 or better, (2) no ocular conditions expected to affect peripheral vision (eg, glaucoma, cataract, retinal pathology), and (3) no developmental delay that could limit testing ability. No patients with a diagnosis of nystagmus or strabismus were included in this study of normal eyes of children. Informed consent was acquired from the parents or guardian, with assent of patients >12 years of age.

Testing was performed on undilated patients in a darkened room. Younger patients were allowed to take the test while reclining in an examination chair. The test settings and algorithm used were the revised VisuALL AVA (compared to the publication by Groth and colleagues[6]) standard strategy on a Pediatric 24-2 protocol with Goldmann size III, and included measurement

Table 1. Patient demographics and characteristics

Characteristic	Result (n = 191 eyes of 97 patients)
Age at testing (years), mean ± SD	11.9 ± 3.1
Age breakdown	
6-11, no. (%)	52 (54)
12-14, no. (%)	25 (26)
15-17, no. (%)	20 (21)
Eye (right/left)	96/95
Visual acuity, logMAR, mean ± SD	0.06 ± 0.08
VisuALL	
Average sensitivity, dB, mean ± SD	29.2 ± 6.3
Mean deviation, dB, mean ± SD	−1.82 ± 3.5
Pattern standard deviation, dB, mean ± SD	3.48 ± 1.9
Foveal sensitivity, dB, mean ± SD	32.0 ± 4.7
Test duration, sec, mean ± SD	344 ± 98
Presenting diagnosis	
Myopia or hyperopia, no. (%)	43 (44)
Astigmatism, no. (%)	26 (27)
Headaches or migraines, no. (%)	11 (11)
Subjective visual disturbance, no. (%)	6 (6)

of foveal sensitivity. The testing paradigm for VisuALL is illustrated in Figure 1. For a video of the patient's instructions, seen on the VisuALL headset before the test begins, see Video 1 (available at jaapos.org). Screen captures of the video are seen in Figure 1. Each stimulus is shown to only one eye at a time; however, the device will intermingle the stimuli so that both eyes are tested during the same session. Foveal sensitivity, individual sensitivities at all points, and global indices of mean deviation (MD) and pattern standard deviation (PSD) were recorded.

The following data were collected for each patient: sex, age, and ocular and medical history (including previous visual field testing). A point-by-point average of sensitivities across all field points were created to assess for normative values. Statistical analysis was performed in R (v 4.0.2 [macOS]) using linear-mixed effect modeling to account for the use of both eyes to assess the relationship of test duration, age, false positives, stereoacuity (by Titmus stereo test) and refraction with global indices such as MD and PSD.

Results

A total of 204 eyes of 102 children were tested. Thirteen eyes of 8 patients were excluded for visual acuity worse than 20/40, leaving 191 eyes of 97 healthy participants (54% female), with mean age of 11.9 ± 3.1 years. Detailed patient demographics and characteristics can be found in Table 1. The VisuALL 24-2 mean sensitivity was 29.2 ± 6.3 dB (mean of point-by-point averages depicted in Figure 2), mean MD was −1.82 ± 3.5 dB, mean PSD was 3.48 ± 1.89 dB, and mean foveal sensitivity was 32.0 ± 4.7 dB. Mean test time was 344 ± 98 sec/eye. Fifty-nine eyes (30.9%) had MD < −2 dB. Only 4 patients (4%) had undergone conventional HVF testing prior to VisuALL field testing. By Titmus stereo test, 53 of 97 patients (55%) had excellent stereoacuity (9/9 circles), and 76 (78%) had acceptable stereoacuity (≥7/9 circles).

Linear mixed effect modeling demonstrated a statistically significant relationship of MD and PSD with test duration ($P < 0.001$ for each; Figure 3A-B), where worse performance was associated with longer test duration. There was a statistically significant relationship of both MD and PSD with age ($P < 0.001$ for each; Figure 3C-D), where worse performance was associated with younger age.

After adjusting for age as a covariate, none of the following variables were significantly associated with improved test performance in terms of either MD or PSD (scatterplots for associations shown in eSupplement 1, available at jaapos.org): false positive rate ($P = 0.44$ and 0.10, resp.), wearing spectacles ($P = 0.07$ and 0.09, resp.), Titmus stereoacuity ($P = 0.20$ and 0.07, resp.), or refractive error ($P = 0.12$ and 0.52, resp.). Subanalysis of

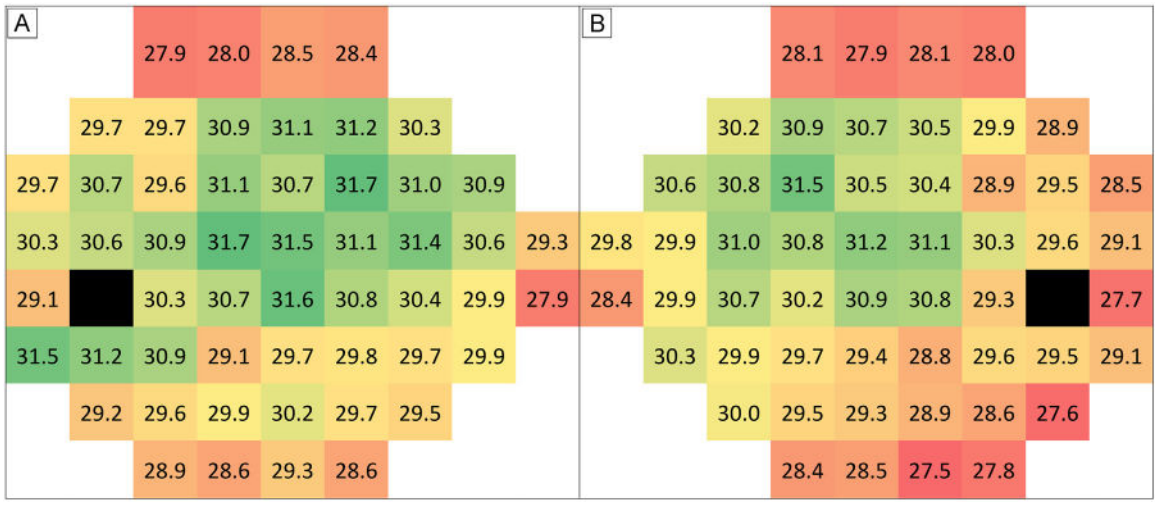

FIG 2. Heatmap distribution of point-by-point average analysis of the VisuALL visual field sensitivities plot in decibels (dB) for all patients in the (A) left eye and (B) right eye. Black indicates the blind spot. In the heat map, red represents the lowest numbers; dark green, the highest numbers.

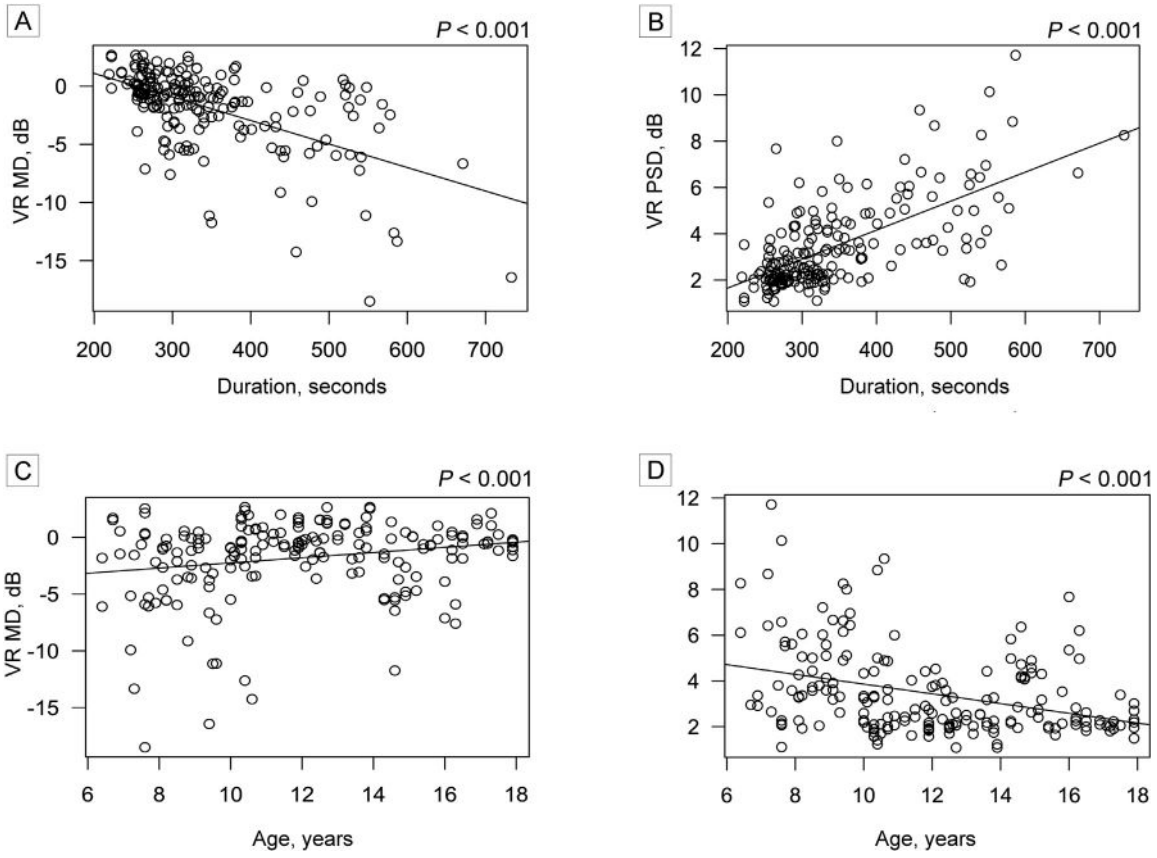

FIG 3. Scatterplot demonstrating the relationship of mean deviation (A) and pattern standard deviation (B) to the duration of testing in seconds and of mean deviation (C) and pattern standard deviation (D) to the age of participants in years. *MD*, mean deviation; *PSD*, pattern standard deviation.

only the 118 eyes that achieved a visual acuity of 20/20 indicates no significant changes to the results (scatterplots for associations with MD and PSD shown in eSupplements 2-3, available at jaapos.org).

Discussion

This study demonstrates the feasibility of using VisuALL, a game-based virtual reality visual field system, with the Pediatric 24-2 AVA Standard in a healthy pediatric population. The test was well tolerated in our study cohort, most of whom had not previously experienced a visual field test. Most patients performed well on the test, with MD > −2 dB in 69% of tests. With the exception of 4 children, this represented the first visual field test these children had performed.

There exists relatively little information on the use of VisuALL field testing in children. The only previously published study in children used a different and longer testing strategy, with comparable results to our study.[6] Our finding for mean overall sensitivity is similar to findings described by Groth and colleagues[6] (29.2 ± 6.3 dB vs 31.8 ± 1.1 dB, resp.); however, our patient population was slightly younger than theirs (11.9 ± 3.1 vs 13.0 ± 2.6 years, resp.). And because they used a longer testing strategy than we did in our current normative testing, our average testing time was predictably shorter[6] (344 ± 98 vs 454 ± 89 sec/eye, resp.). The streamlined game-based VR testing used in this study compared favorably against non-game-based VisuALL testing reported in adults (368 sec/eye).[8] Our patient population demonstrated a decline in sensitivity to the periphery (Figure 2). Although this decline in sensitivity peripheral to the fovea is expected, given the "normal" hill of vision found with standard HVF, it was not seen in the study by Groth and colleagues.[6] One difference to note is that VisuALL uses scotopic 1 cd/m^2 testing conditions in which a white stimulus is shown against a black background,[11] whereas HVF standard perimetry uses a white stimulus projected on a white background, producing photopic conditions in which cones are primarily tested.[12] This difference between the devices may be the reason the central hill of vision is not consistently detected in studies of the VisuALL system, and may result in differences in measured sensitivities between the two perimetry devices. Despite this difference in testing modalities, previous studies on adults[8] have demonstrated that VisuALL perimetry successfully discriminates healthy subjects from mild or moderate glaucoma patients and correlates well with HVF.

The association of poor test performance with younger age and longer duration is consistent with previously published literature in adults.[13,14] Longer test duration often results from inattention or severe field deficits, hence the association with poorer test results. Because our patient population was otherwise healthy, no field abnormalities would be expected. Therefore, poor field MD or PSD were taken as indicators of poor test taking ability. Published studies report that children begin to perform HVF with acceptable reliability at 7-9 years[6] and commence testing competently around 12-14 years.[5] In this study, some children as young as 6 years of age were able to perform reliable VisuALL fields. However, further studies are necessary to demonstrate whether a game-based VisuALL algorithm can actually expand the range of ages where reliable field testing is possible.

Other than younger age and longer test time, no other variables were found to be associated with poor field test performance once the effect of age was considered. One possible explanation for stereoacuity not appearing to be a factor despite the binocular testing format is that the targets are flashed into only one eye at a time, eliminating any role for binocular function to help or impede recognition of the target. In addition, patients with strabismus or significant amblyopia were excluded from the study. Because age was a statistically significant covariate (with younger patients showing poorer performance), it is also possible that young children similarly did not perform stereoacuity testing reliably. Additional studies are necessary to elucidate the effects of mild amblyopia and poor stereoacuity on these binocular field tests. A benefit of virtual reality field testing is that patients are allowed to wear their own spectacles, which should eliminate both refractive error and spectacle wear as a factor in poor test performance.

Limitations of this study include the limited number of participants, lack of data regarding test-retest reproducibility, and a lack of comparison between the performance of the VisuALL paradigm versus a standard perimetry such as HVF. It is unclear at this time how nystagmus affects virtual reality field testing. The current version of the device is not equipped to test patients with strabismus; however, future versions incorporating eye tracking will be able to account for eye misalignment during the field test.

VisuALL could alleviate some of the limitations of conventional perimetric devices, making visual field testing more accessible, cost effective, and convenient for both patients and clinicians.[6] The ease of testing, comfort, and game-based testing modality has the potential to improve the experience of visual field testing in children, although VR visual field testing is still at an early stage of development and future research is required for further validation.

In conclusion, age and test duration influenced MD and PSD, consistent with previous literature. Virtual reality game-based perimetry is well tolerated in a pediatric cohort and may prove valuable as an in-office and perhaps also home-based alternative to standard table-based testing. Future studies are necessary to evaluate the performance of VisuALL in different settings, including clinic- and home-based testing, and in children with various ocular pathologies.

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