

Automated Perimetry in Children with Suspected and Known Glaucoma: Virtual Reality Versus Tabletop

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Abstract

Humphrey visual field (HVF)-equivalent virtual reality fields (VRFs) have shown promise in adult glaucoma. Research comparing HVF-equivalent VRF to standard automated perimetry (SAP) in pediatric glaucoma is limited. We aimed to evaluate agreement and concordance between HVF-equivalent VRF and SAP for children with glaucoma.

This prospective study enrolled children with known or suspected glaucoma. Participants completed HVF then VisuALL HVF-equivalent VRF at one visit. A masked ophthalmologist graded visual fields for defects and location. Global parameters were compared between devices. A point-by-point deviation plot analysis was performed.

A total of 60 patients (116 eyes) were included, mean age 13.1 ± 2.93 years. Mean retinal nerve fiber layer thickness was 86.1 ± 21.20 μm . Average mean deviation (MD), pattern standard deviation (PSD), and foveal sensitivity significantly differed for HVF versus VRF. There was moderate association between HVF and VRF for MD ($P < 0.001$) and PSD ($P < 0.001$). Concordance by region for any defect was 76.2%; point-by-point match rate for total deviation plots was 75.8%. Test duration was longer for HVF versus VRF (4.17 ± 1.19 vs. 2.10 ± 0.18 minutes, respectively, $P < 0.001$). Most children (98%) preferred VRF over HVF.

HVF and HVF-equivalent VRF testing modalities yielded moderate association. HVF-equivalent VRF offers a shorter test that children preferred and may supplement SAP.

INTRODUCTION

Assessing visual field defects is essential for diagnosing and managing adult glaucoma,¹ but it remains challenging in children because of shorter attention spans, fatigue, and variable test reliability.² Standard automated perimetry using Humphrey Visual Field (HVF) testing is the clinical reference standard. As virtual reality technology becomes more accessible,³ virtual reality fields (VRFs) have shown promise for pediatric perimetry, demonstrating agreement with conventional HVF testing in glaucoma and neuro-ophthalmic diseases.^{4–8} Pediatric studies have largely focused on game-based visual field testing,^{4,6,7,9,10} whereas non-game-based, HVF-equivalent methodology has been evaluated predominantly in adults with glaucoma.⁵ Evidence on the performance of HVF-equivalent VRF relative to tabletop HVF in children with glaucoma remains limited. The purpose of this study was to evaluate VisuALL (non-game-based) HVF-equivalent VRF versus tabletop HVF in children with known or suspected glaucoma.

MATERIALS AND METHODS

The study protocol and consent form were approved by the Institutional Review Board of Duke University Medical Center for this prospective study of children with known or suspected glaucoma. Written

informed consent was obtained from the parent or guardian of all participants, and children provided verbal informed assent, with children 12 years and older providing written assent. All research activity complied with the Declaration of Helsinki and was in accordance with the Health Insurance Portability and Accountability Act (HIPAA).

Children (< 18 years old) with known or suspected glaucoma at Duke University Medical Center under the care of one clinician (SFF) were enrolled prospectively from August 2023 to January 2026. The participants underwent clinically indicated comprehensive eye examinations including intraocular pressure measurement, clinical and optical coherence tomography (OCT) assessment of the optic nerve, and refraction. Patients were identified as having a diagnosis of glaucoma or glaucoma suspect based on the criteria established by the Childhood Glaucoma Research Network classification system.¹¹

As part of routine care, all included patients completed a clinically indicated HVF (Size III stimulus/24 – 2/SITA Fast; Carl Zeiss Meditec, Dublin, CA), followed by a VisuALL HVF-equivalent VRF (Size III stimulus/24 – 2/AVA Fast; Olleyes, Inc.; Summit, NJ) at a single visit. Specifically, data were extracted for the first visit at which the patient completed testing with both modalities. If patients completed HVF and VRF testing without the same testing specifications and settings (e.g., 10 – 2 instead of 24 – 2), they were excluded from the study. Patients who completed only 10 – 2 studies were excluded. VRF testing was conducted using the patients' own spectacles (as the headset is designed to be worn over glasses), with testing on binocular mode (whereby each eye is tested monocularly, but the machine algorithm alternates between eyes and does not require patching), and with eye tracking. All eyes that completed both HVF and VRF testing were included in the analysis, regardless of whether the patient had unilateral or bilateral disease. At the conclusion of both visual field tests, the child was asked to choose which test they preferred (in a neutral fashion), and the response was recorded. This question was implemented partway through the study; therefore, only 44 of 60 patients were queried. Additional details regarding the VisuALL VRF AVA Fast Threshold protocol used in this study can be found in prior studies.^{6–8,10}

An ophthalmologist masked to clinical data (BW) graded both HVF and VRF independently for defects at different points in time to reduce bias. Glaucomatous field defects were defined as 3 clustered abnormal points depressed by at least 5 dB from normative values with their location categorized by quadrants (superotemporal, superonasal, inferotemporal, inferonasal). The central 4 points of fixation were also graded for assessment of fixation-threatening field loss. Global indices (mean deviation, MD, and pattern standard deviation, PSD) and foveal sensitivity (FS) were recorded and compared between the two testing modalities. A point-by-point analysis was completed to calculate and compare the match rates for each eye of each participant for both the total deviation and pattern deviation plots. For each 24 – 2 plot, only locations marked by a filled black square ($P < 0.5\%$) were considered defects. All other marks were considered non-defects. For each eye, the match rate was the number of concordant locations divided by the 52 test locations, expressed as a percentage. Total deviation and pattern deviation plots were analyzed separately. Reported match rates represent the mean across all included eyes. Representative point-by-point analyses are shown in Fig. 1.

For all included eyes, optical coherence tomography (OCT, Spectralis) retinal nerve fiber layer (RNFL) thickness and ganglion cell layer (GCL) volume values were collected for patients if completed within a year from the HVF and VRF date, and clinically stable over the interval. RNFL measurements were available for 99 out of 116 eyes and GCL for 91 out of 116 eyes. In a subgroup analysis restricted to eyes with more severe structural damage (average RNFL thickness < 70 μm on OCT; $n = 19$ eyes), defects in each region were scored as present or absent on both HVF and VRF.⁶

Statistical analysis was performed in R (version 4.5.2) using linear mixed-effects (LME) models with subject-specific random intercept to account for inter-eye correlation. Separate models were fit to assess the association between VRF and HVF for global parameters (MD, PSD) and FS. Marginal variance R^2_M , representing the variance explained by the fixed effects only, is reported. Bland-Altman plots were used to compare MD, PSD, and FS between the two modalities with 95% limits of agreement. Additional analyses of the point-by-point data using LME models assessed the relationship of testing duration, age, RNFL thickness and GCL volume values, and visual acuity, with total and pattern deviation match rates.

RESULTS

A total of 116 eyes from 60 patients were included. Mean age was 13.1 ± 2.93 years. Seventy eyes had a diagnosis of glaucoma (60%), while 29 eyes were classified as glaucoma suspects (25%). Of the 116 included eyes, 17 (15%) were unaffected fellow eyes of a child with glaucoma or glaucoma suspect diagnosis in the other eye. Mean visual acuity was 0.20 ± 0.30 (logMAR). Mean RNFL thickness and GCL volume were $86.1 \pm 21.20 \mu\text{m}$ and $0.99 \pm 0.15 \text{ mm}^3$, respectively. At the time of testing, 52 (44.8%) of the included eyes were naïve to HVF and 76 (65.5%) were naïve to VRF. Patient demographic characteristics are summarized in Table 1.

Table 1
Patient demographics and characteristics

Patient Characteristics	<i>n = 60 patients (116 eyes)</i>
Age, years	13.1 ± 2.93 (6.0–17.9)
Visual Acuity (logMAR)	0.20 ± 0.30 (0–2)
Visual Field Experience [⊠]	
HVF Naïve, no. eyes (%)	52 (44.8%)
VRF Naïve, no. eyes (%)	76 (65.5%)
OCT Findings [†]	
RNFL, μm	86.1 ± 21.20 (33–134)
GCL, mm ³	0.99 ± 0.15 (0.57–1.5)
Diagnosis, no. eyes (%)	
Glaucoma secondary to non-acquired conditions (<i>e.g., anterior segment dysgenesis, Sturge-Weber</i>)	21 (18%)
Glaucoma secondary to acquired conditions (<i>e.g., uveitis, trauma</i>)	6 (5%)
Primary congenital glaucoma (PCG)	19 (16%)
Juvenile open angle glaucoma (JOAG)	13 (11%)
Glaucoma following cataract surgery (GFCS)	11 (9%)
Glaucoma suspect	29 (25%)
Normal fellow eye of unilaterally affected children	17 (15%)
Abbreviations: HVF = Humphrey visual field; VRF = Virtual reality field; OCT = optical coherence tomography; RNFL = retinal nerve fiber layer; GCL = ganglion cell layer	
[⊠] Naïve status reflects eyes with no prior testing experience on the respective platform. Percentages may not sum to 100% because some eyes were naïve to both, one, or neither modality. [†] RNFL measurements were available for 99/116 eyes and GCL in 91/116 eyes. Data are presented as mean ± SD (range) unless otherwise stated.	

All patients included in the study completed both HVF and VRF testing. Figure 1 shows examples of both highly concordant (Fig. 1a) and less concordant (Fig. 1b) visual field tests by the point-by-point analysis. Average point-by-point match rates of total deviation and pattern deviation in HVF versus VRF were 75.8% and 80.2%, respectively (Table 2). For all eyes included in the study, the concordance between HVF and VRF for presence or absence of any defect by location (quadrants and center) was 76.2% (Table 2, **Supplementary Fig. S1**).

Table 2
Humphrey Visual Field (HVF) and Virtual Reality Field (VRF):Global Parameters and Agreement

Testing Parameters	HVF <i>n</i> = 116 eyes (60 patients)	VRF <i>n</i> = 116 eyes (60 patients)	P Value
Mean deviation, dB	-6.50 ± 7.36	-5.17 ± 7.17	0.039
Pattern standard deviation, dB	3.99 ± 3.21	4.78 ± 3.27	0.015
Foveal sensitivity, dB	33.43 ± 7.07	31.28 ± 6.59	0.005
Test duration, minutes	4.17 ± 1.19	2.10 ± 0.18	< 0.001
HVF vs. VRF Agreement (%)			
Regional (average of 5 zones) [⊠]	76.2		
Total deviation point-by-point (%)	75.8 ± 23.8		
Pattern deviation point-by-point [†] (%)	80.2 ± 21.1		
Values are mean ± standard deviation.			
[⊠] Visual field locations were grouped into five regions: superotemporal (ST), superonasal (SN), inferonasal (IN), inferotemporal (IT), and center. Regional concordance is shown in Supplementary Fig. S1.			
[†] Pattern deviation point-by-point match rate was unable to be calculated for 6 eyes as they lacked a pattern deviation plot and were excluded from that calculation.			

Average MD and PSD significantly differed for HVF vs. VRF (-6.50 ± 7.36 vs. -5.17 ± 7.17 dB, P = 0.039; and 3.99 ± 3.21 vs. 4.78 ± 3.27 dB, P = 0.015, respectively). Average FS was lower in VRF (33.43 ± 7.07 vs. 31.28 ± 6.59 dB, P = 0.005). Per-eye test duration was significantly longer for HVF vs. VRF (4.17 ± 1.19 vs. 2.10 ± 0.18 minutes, P < 0.001; Table 2). There was moderate association between HVF and VRF for MD ($R^2_M=0.524$, P < 0.001) and for PSD ($R^2_M=0.561$, P < 0.001), and weak association for FS ($R^2_M=0.123$, P < 0.001) (Fig. 2). Bland-Altman analysis demonstrated increasing variability among the global indices and FS with worse disease severity, but no other systematic bias (Fig. 3). Age was not significantly associated with the absolute difference between HVF and VRF for most global parameters, with only PSD showing a very weak association ($R^2_M=0.060$, P = 0.009).

Using HVF duration as a marker of poor reliability, there was a significant association between longer test duration and poor point-by-point match rate in total deviation ($P < 0.001$) and pattern deviation ($P = 0.001$) (**Supplementary Fig. S2**). Regarding visual acuity, worse visual acuity was weakly associated with a lower match rate for total deviation ($P = 0.010$) and pattern deviation ($P = 0.002$) (**Supplementary Fig. S3**). In patients with an OCT RNFL $< 70 \mu\text{m}$ ($n = 19$), VRF identified any field defects in 100% (19/19) of eyes, and HVF identified field defects in 94.7% (18/19).

Forty-four children were specifically queried regarding their preference of HVF versus VRF. Forty-three (98%) stated they preferred the VRF testing modality.

DISCUSSION

This study compares the performance of VisuALL HVF-equivalent VRF, a non-game-based VRF, to the standard tabletop HVF in a pediatric glaucoma and glaucoma suspect population. The findings of this study add to the growing literature supporting VRF as a potential adjunct to standard tabletop perimetry in pediatrics, most of which used game-based VRF.^{4,6–8} Our results demonstrate that VisuALL HVF-equivalent VRF is moderately associated with tabletop HVF for global parameters (MD and PSD), with significantly shorter testing time. These findings align with previous work using game-based VRF in children with glaucoma⁷ and neuro-ophthalmic conditions,⁴ where MD and PSD consistently outperformed FS. This pattern likely reflects the inherent variability in global parameters versus a single point test like FS.

Bland-Altman plots revealed no mean bias for MD, PSD, or FS. However, variability widened in more advanced disease, a pattern also observed with conventional perimetry in previous studies.^{4,6} Despite the expectation that testing reliability would improve with age,¹² age was not significantly associated with the absolute difference between HVF and VRF for most global parameters, with only PSD showing a very weak association. Because prolonged test duration is a well-documented marker of reduced HVF reliability,¹³ it is not surprising that increased duration was also associated with a poorer match rate.

When we evaluated the subset of eyes with OCT RNFL $< 70 \mu\text{m}$ ($n = 19$), in whom we expected visual field defects, VRF identified defects in all 19 eyes (100%) and HVF in 18 (94.7%), suggesting both tests are able to identify field loss in this population.

Reliable visual field assessment in children remains challenging due to attention limitations, fatigue, and learning effects. Previous studies have suggested that despite these concerns, patients younger than 10 years old may sometimes produce high-quality results when tested with static perimetry.¹⁴ In this study, VRF testing required approximately half the time per eye compared with tabletop HVF and was preferred by most queried participants. Reduced testing duration may improve tolerance and clinic workflow in pediatric settings, where cooperation and attention span are important determinants of test success. In addition, the ability to perform HVF-equivalent testing in a portable, head-mounted format may offer advantages in certain clinical contexts, including patients with positioning difficulties or limited access

to tabletop perimetry. VRF testing also offers the possibility of remote visual field testing for closer monitoring in selected patients at high risk for progression.

Our findings should be considered in light of several limitations. Due to the relative rarity of pediatric glaucoma, the sample size is small and includes a heterogeneous diagnostic cohort. As a cross-sectional comparison, this study does not assess longitudinal progression or test-retest repeatability, both essential for determining whether virtual reality platforms could be used as a substitute for conventional perimetry. Moreover, because HVF was consistently administered before VRF to prioritize the clinical gold standard, our findings may have been influenced by order-related effects, including learning and testing fatigue. Enrollment was also limited to children for whom conventional perimetry was clinically indicated and feasible. Consequently, our results reflect children able to complete standard tabletop perimetry and may not generalize to younger children. Also, point-by-point match rates may be dominated by agreement at nondefective locations, particularly in fellow eyes, which are presumed to be normal. In addition, reliability indices for VRF at this time are not directly comparable to HVF as they are derived using different methods.^{4,7} The lack of comparable reliability indices is currently a weakness of the VRF used in this study. Notably, the two platforms also differ in their testing conditions. Standard HVF presents a white stimulus against a uniformly illuminated background, whereas the VisuALL headset displays stimuli against a substantially darker, lower-luminance background.⁸ These differences in background luminance and contrast may contribute to the observed differences in MD and PSD, independent of any true difference in visual function. Further, we did not assess test-retest repeatability for HVF or VRF in this particular study, though it has been demonstrated in prior studies using this device.⁹ Each child completed a single VRF during a clinically indicated visit, which often tested the limits of their attention. Future studies evaluating repeatability, and utility in longitudinal management of childhood glaucoma, especially in eyes with clinical progression, will further clarify the role of virtual reality perimetry in pediatric glaucoma management.

HVF and HVF-equivalent non-game-based VRF testing modalities show moderate association for global parameters in children with known and suspected glaucoma. Compared with HVF, VRF offers shorter testing times, is preferred by most children queried, and may serve as a useful supplement to tabletop automated perimetry in this population.

Declarations

Additional Information:

This study was approved by Duke University's Institutional Review Board (Pro00109426). Written informed consent was obtained from the parent or guardian of all participants, and children provided verbal informed assent, with children 12 years and older providing written assent. All research activity complied with the Declaration of Helsinki and was in accordance with the Health Insurance Portability and Accountability Act (HIPAA). The study adhered to the tenets of the Declaration of Helsinki.

Competing Interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: MAE is a site principal investigator for a Viridian clinical trial. SFF has a device on loan from Olleyes (Summit, NJ). BW has research funding from Knights Templar and is part of the editorial team at Scientific Reports. NP, JL, and ZS (current or former research coordinators) are or were supported through funding from Saving Kids' Sight Foundation and the Lions Eye Foundation. All other authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Author Contribution

Stephanie M. Tillit and Nikita Piryani contributed equally to this paper. Conception and design: SFF, BW. Acquisition of data: JL, ZS. Analysis and interpretation of data: SMT, NP, BW, JL, SFF. Formal statistical analysis: BW. Drafting the article: SMT, NP. Critical revision of the article: SMT, NP, BW, MAE, SFF. Supervision and project administration: SFF. Final approval of the version to be published: All authors. Guarantor: SFF accepts full responsibility for the finished work and the conduct of the study, had access to the data, and controlled the decision to publish.

Data Availability

The data used in this manuscript are not publicly available due to the protection of personal patient information. However, data may be shared upon reasonable request from clinicians or researchers affiliated with recognized academic or medical institutions. Please email corresponding author (SFF) for any related inquiries.

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Figures

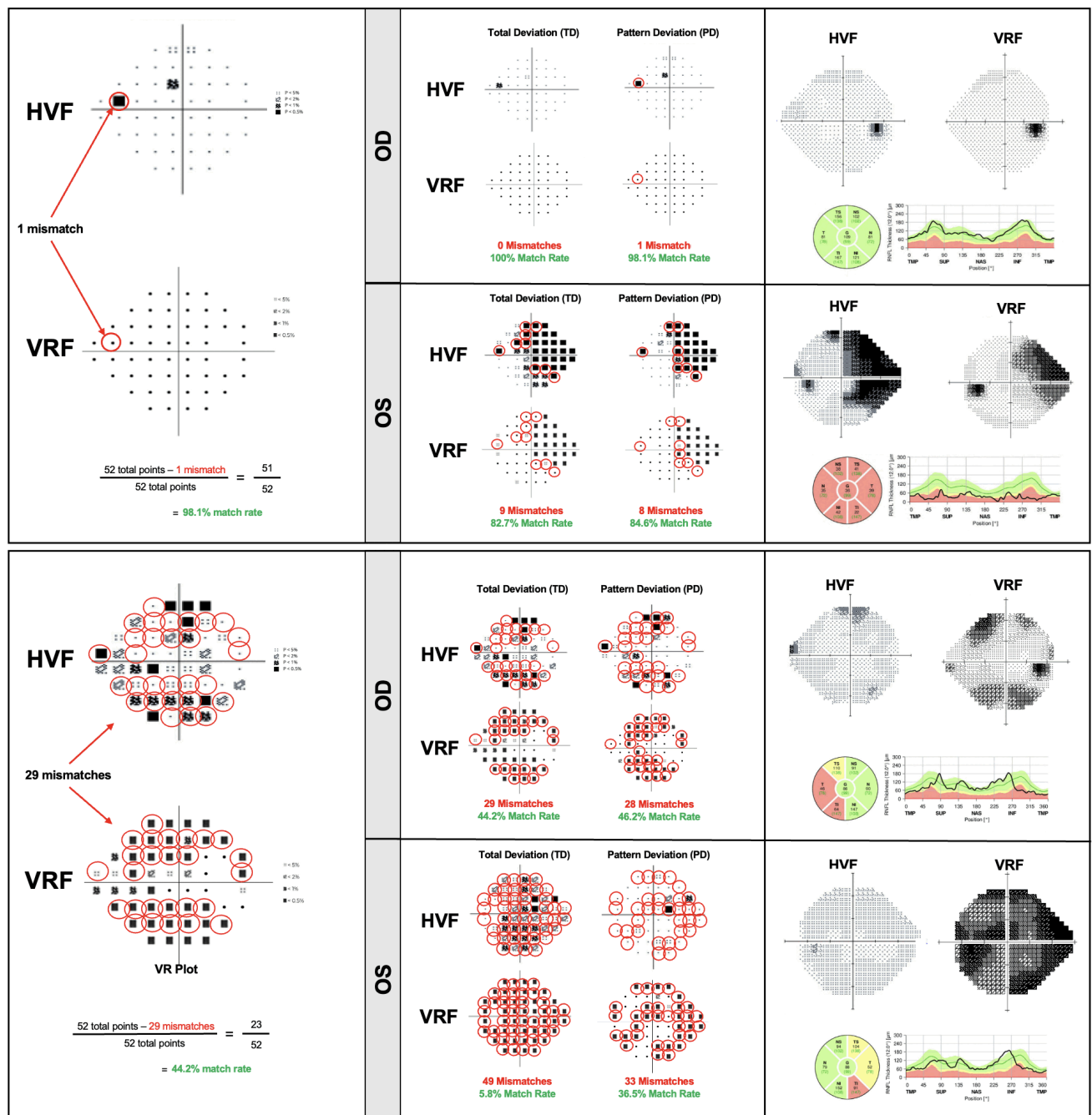


Figure 1

Examples of Humphrey visual field (HVF) and virtual reality visual field (VRF) in (a) a patient testing with a good match rate and (b) a patient testing with a poor match rate. (a) Point-by-point analysis of HVF and VRF probability plots demonstrating a good match. The left panel shows the pattern deviation (PD) plots for HVF and VRF of a patient's right eye, yielding 1 mismatch and a 98.1% match rate. The middle panel displays total deviation (TD) and PD probability plot comparisons for two eyes (OD and OS of the same patient), a 16-year-old with ocular hypertension OD and primary congenital glaucoma OS, with corrected vision 20/20 OU (OD: mean deviation [MD] -0.11, pattern standard deviation [PSD] 1.87; OS: MD -17.92, PSD 14.83). Right panel shows corresponding HVF and VRF grayscale plots alongside

optical coherence tomography (OCT) retinal nerve fiber layer (RNFL) thickness maps. **(b) Point-by-point analysis of HVF and VRF probability plots demonstrating a poor match.** The left panel shows the TD plots for HVF and VRF of a patient's right eye, yielding 29 mismatches and a 44.2% match rate. Middle panel displays TD and PD probability plot comparisons for two eyes (OD and OS of the same patient), a 14-year-old female with primary congenital glaucoma OU with visual acuity of 20/20 OD and 20/30 OS (OD: MD -4.57, PSD 4.55; OS: MD -4.48, PSD 1.84). Right panel shows corresponding HVF and VRF grayscale plots alongside OCT RNFL thickness maps.

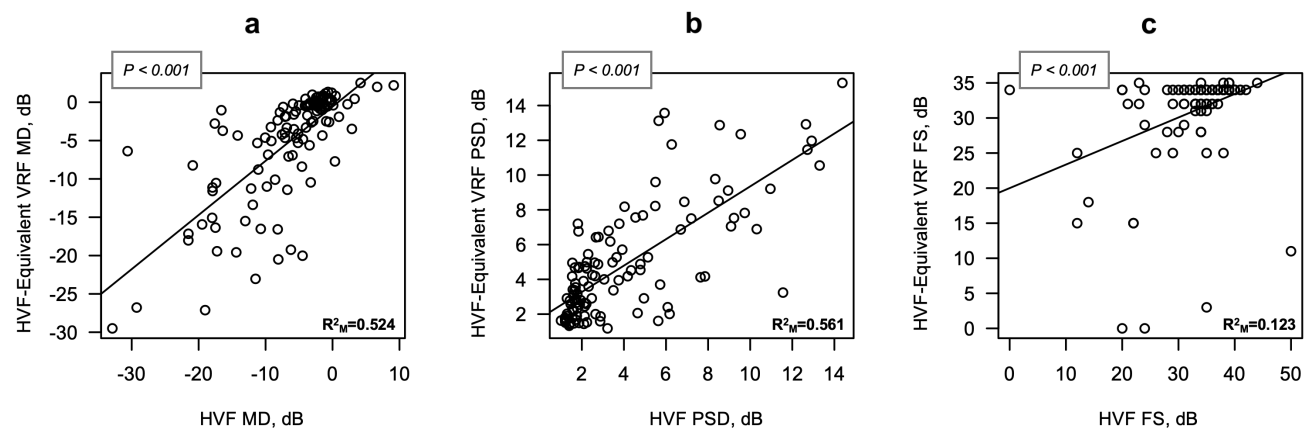


Figure 2

Scatterplot demonstrating the relationship between tabletop Humphrey visual field (HVF) and HVF-equivalent virtual reality visual field (VRF) for **(a)** mean deviation (MD), **(b)** pattern standard deviation (PSD), and **(c)** foveal sensitivity (FS). There was moderate association between HVF and VRF for MD ($R^2_M=0.524$, $P<0.001$) and for PSD ($R^2_M=0.561$, $P<0.001$), and weak association for FS ($R^2_M=0.123$, $P<0.001$).

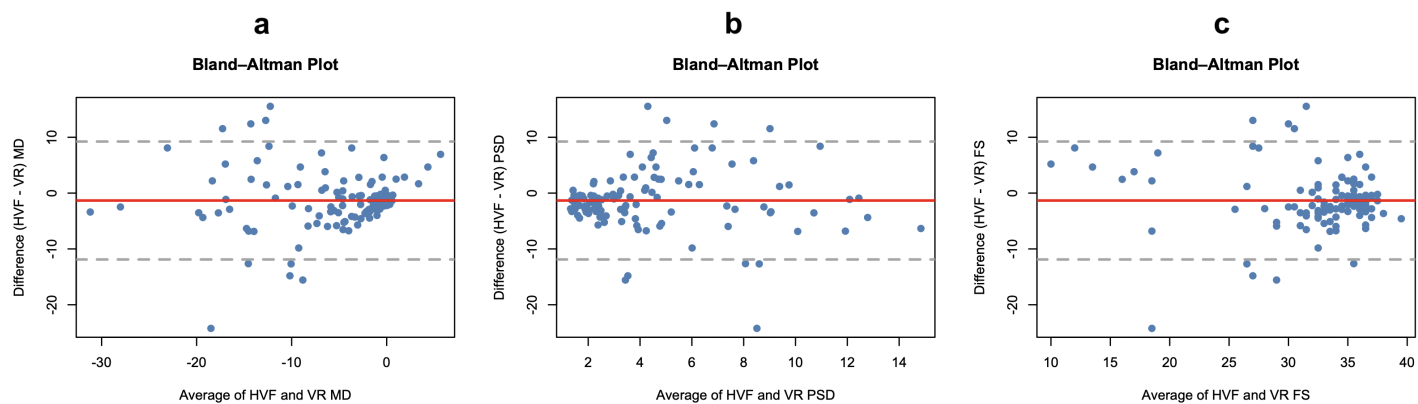


Figure 3

Bland-Altman analyses of global indices for **(a)** mean deviation (MD), **(b)** pattern standard deviation (PSD), and **(c)** foveal sensitivity (FS) comparing Humphrey visual fields (HVF) and HVF-equivalent virtual reality fields (VRF). The red line indicates average systematic difference; the dashed grey lines indicate 95% limits of agreement. There is increasing variability among the global indices and FS with worse disease severity, but no other systematic bias.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryFigures.pdf](#)