Use of a binocular optical coherence tomography system to evaluate strabismus in primary position

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Running Head:

Automated, quantitative assessment of strabismus using binocular OCT

Keywords:

Binocular

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Strabismus

Abbreviations:

APCT - Alternating Prism Cover Test

OCT – Optical Coherence Tomography

LoA – Limits of Agreement

Figures:

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Key Points

Question: Can a new form of optical coherence tomography (OCT) known as 'binocular OCT' be used to measure the size of strabismus?

Findings: This study included 15 participants with strabismus and 15 healthy individuals. Binocular OCT imaging correctly revealed the type and direction of the deviation in all participants, including both horizontal and vertical deviations. The size of strabismus measured with binocular OCT had fair agreement with the alternating prism cover test.

Meaning: Binocular anterior segment OCT imaging can provide clinicians with a precise measurement of strabismus, which may be useful for diagnosis and monitoring.

Abstract

Importance: Current clinical methods for assessing strabismus can be prone to error. Binocular OCT has the potential to assess and quantify strabismus objectively and in an automated manner.

Objective: To evaluate the use of a binocular optical coherence tomography (OCT) prototype to assess the presence and size of strabismus.

Design, Setting, and Participants: Fifteen participants with strabismus recruited from Moorfields Eye Hospital NHS Foundation Trust, London, UK, and fifteen healthy volunteers underwent automated anterior segment imaging using the binocular OCT prototype. All participants had an orthoptic assessment including alternating prism cover test (APCT) prior to imaging. Simultaneously acquired pairs of OCT images, captured with one eye fixating, were analysed using ImageJ to assess the presence and angle of strabismus.

Main Outcomes and Measures: The direction and size of strabismus measured using binocular OCT was compared to that found using APCT.

Results: The median age for participants with strabismus was 55 years (interquartile range 33-66.5 years), and 50 years (interquartile range 41-59 years) for healthy group. The median magnitude of horizontal deviation was 20Δ (interquartile range 13-35Δ), and 3Δ for vertical deviation (interquartile range 0-5Δ). Binocular OCT imaging correctly revealed the type and direction of the deviation in all 15 strabismus participants, including both horizontal and vertical deviations. APCT and OCT measurements were strongly correlated for both horizontal (Pearson's $r = 0.85$, 95% confidence interval (CI) 0.60-0.95; $P < 0.001$) and vertical ($r = 0.89$, CI 0.69-0.96; $P < 0.001$) deviations. In the healthy cohort, 9 participants had a latent horizontal deviation on APCT (median magnitude 2Δ, range 2-4Δ). Six were orthophoric. Horizontal deviations were observed on OCT imaging in 12 of the 15 participants, and a vertical deviation was visible in 1 participant.

Conclusions and Relevance: These findings suggest that binocular anterior segment OCT imaging can provide clinicians with a precise measurement of strabismus. The prototype can potentially incorporate several binocular vision tests that will provide quantitative data for the assessment, diagnosis, and monitoring of ocular misalignments.

Introduction

Strabismus is a common condition that can affect both children and adults.[1, 2] Clinical assessments designed to measure ocular misalignment often require specialist orthoptic expertise and good patient cooperation. An alternating prism cover test (APCT) is most commonly used, however, the endpoint of such testing can be subtle or variable, and is prone to inter- and intra-observer error, particularly in less cooperative children.[3, 4] Electronic instruments that use infrared light to track eye position of both eyes simultaneously such as video goggles[5] and gaze trackers[6] have been developed to increase the precision of measurement but are mainly used for research purposes.

Optical coherence tomography (OCT) devices are becoming ubiquitous to eye clinics as they provide objective and quantitative data about ocular structures to aid the diagnosis and monitoring of eye disease. In this report we demonstrate an application of a prototype binocular optical coherence tomography system (Envision Diagnostics, El Segundo, CA) that acquires anterior segment images of both eyes simultaneously, even with one eye fixating, and in an automated manner. By analyzing simultaneously acquired pairs of anterior segment images, the presence of strabismus can be identified. We evaluate the use of anterior segment OCT as a method of assessing strabismus and measuring the angle of deviation.

Methods

Participants with strabismus were prospectively recruited from clinics at Moorfields Eye Hospital NHS Foundation Trust, London, UK, as part of the EASE study (ClinicalTrials.gov Identifier: NCT02822612). Healthy volunteers were recruited from staff members at the hospital. Written informed consent was obtained from all participants in the study. All participants were required to have no significant hearing impairment that would affect their ability to respond to instructions delivered by the device. A conversational level of English was required for users to understand the instructions, and to be able to communicate with the device via an English language voice recognition system. No participants were excluded based on disease status to ensure our cohort consisted of everyday users of eye care services. All underwent orthoptic assessment prior to binocular OCT examination, including visual acuity measurement and APCT at distance in primary position, with habitual refractive error correction if appropriate. Approval for data collection and analysis was obtained from a UK National Health Service Research Ethics Committee (London-Central). The study adhered to the tenets of the Declaration of Helsinki.

Binocular OCT examination

All participants underwent binocular OCT examination as described elsewhere.[7] Briefly, this is an automated prototype device that acquires OCT images of the anterior and posterior segments of both eyes simultaneously using a tunable swept-source laser without requiring an operator. The device uses a Maxwellian view system to simulate distance fixation. The fixation target was presented to the non-deviating eye in the strabismus group, selected manually prior to examination. Therefore, the primary deviation was measured on OCT. For healthy participants, the target was presented to the dominant eye (right eye in all participants). The spherical equivalent of the user's habitual refractive error is corrected within the device.

Measurement of angle

A volume comprising 128 B-scans of the anterior segment was acquired by the device in the horizontal and vertical planes. Only a single central anterior segment image was used for each plane for analyses. The central image can be deduced by the visualization of the corneal vertex reflection in the fixing eye.[8] This hyperreflective line was used as a surrogate for the visual axis. The image captured at the same time point was used for the fellow non-fixing eye. The images were adjusted to 16.5x14.9 aspect ratio as they are acquired at 16.5mm width and 14.9mm depth. ImageJ, a widely use open-source Java image analysis program was used to measure the difference in angle in degrees between the fixing and non-fixing eye. A line was drawn between the pupil margins at the posterior epithelium of the iris for both eyes. These landmarks were chosen as they were visible in both horizontal and vertical scans. The angle between the lines was calculated as the angle of deviation (Figure 1).

Outcome measures

1. The direction of the deviation was determined by the direction of the fellow eye with respect to the fixating eye in both horizontal and vertical scans. This was compared to the direction of the misalignment found using APCT for distance fixation.
2. The size of the misalignment was compared to that found using distance APCT. Values in prism diopters (Δ) were converted to degrees using the following formula:[9]

$$\text{degrees} = \tan^{-1}(\Delta/100) \times 180/\pi$$

Results

Twelve participants had concomitant strabismus, one of which had glaucoma and strabismus. One participant had a decompensated strabismus as a consequence of loss of vision after a retinal detachment. Two participants had an acquired restrictive incomitant strabismus related to sphenoid wing meningioma, and thyroid eye disease. These are described further in Table 1. The median age was 55 years (interquartile range 33-66.5 years). Thirteen subjects were Caucasian, and two subjects were Asian. Seven of the 15 subjects were female. The median magnitude of horizontal deviation was 20Δ (interquartile range 13-35Δ), and 3Δ for vertical deviation (interquartile range 0-5Δ). Mean spherical equivalent was +0.53D ±2.19 (range sphere -2.50 to +5.50DS, range cylinder 0 to -3.50DC). The cohort of healthy participants had no manifest deviation. Nine healthy participants had a latent deviation for distance, and 6 were orthophoric. The median age of this group was 50 years (interquartile range 41-59 years). Twelve healthy participants were Caucasian, two were Asian, and one subject was Black. Eight of the healthy participants were female. Mean spherical equivalent for this cohort was -0.51D ±1.45 (range sphere -3.50 to +2.75DS, range cylinder 0 to -2.50DC). All participants understood the examination and were cooperative, as discussed further in a usability study of the device.[7]

Direction and size of misalignment

Orthoptic assessment revealed five participants in the strabismus group had a horizontal deviation only, one participant had a vertical deviation only, and nine participants had both horizontal and vertical deviations. A torsional element was not detected in any participants. Binocular OCT imaging correctly identified the direction of misalignment in all 15 strabismus participants, including both horizontal and vertical deviations. Three out of the five participants assessed as having a horizontal deviation only using APCT were also found to have an additional vertical deviation on binocular OCT imaging (Table 1).

There was a strong correlation between the measurement of strabismus using APCT and the measurement calculated from the OCT images for both horizontal (Pearson's $r=0.85$, 95% confidence interval (CI) 0.60-0.95; $P<0.001$) and vertical ($r=0.89$, CI 0.69-0.96; $P<0.001$) deviations. The confidence intervals indicate a strong relationship between the two methods. Bland-Altman[10] plots show heteroscedasticity where the agreement between the methods decreases as the size of the deviation increases. There was a mean difference of -0.30° (~ -0.52Δ) for horizontal misalignment and -2.20° (~ -3.84Δ) for vertical misalignment. The 95% limits of agreement (LoA) for horizontal misalignment were between 9.55° (~ 16.82Δ) and -10.16° (~ -17.55Δ). For vertical misalignment the limits of agreement were narrower between 2.66° (~ 4.65Δ) and -7.06° (~ -12.38Δ). Regression on the Bland-Altman plots show no significant proportional bias for horizontal misalignments ($P=0.957$), however show a significant relationship for vertical misalignments ($P=0.007$).

In the healthy cohort, 8 had an exophoria (median magnitude 2Δ, range 2-4Δ (1.15-2.29°), one participant had an esophoria measuring 2Δ, and 6 participants were orthophoric, measured using distance APCT. One participant had a vertical deviation on near APCT. No other participants in this group had a vertical or torsional component at distance or near. In the 8 exophoric participants, 6 had a misalignment corresponding to an exo-deviation on OCT (median magnitude 5.25° (~ 9.19Δ), interquartile range, 2.63-6.49° (~ 4.59-11.38Δ), one had an eso-deviation on OCT measuring 8.61° (~ 15Δ), and one participant had no deviation on OCT. From the 6 orthophoric participants, 3 had an exo-deviation on OCT (range 2.93-6.38°) and 1 had an eso-deviation (4.09°). The single participant with an esophoria did not have any measured deviation on the binocular OCT. Two participants measured as orthophoric on APCT was also orthophoric on binocular OCT. A vertical component corresponding to a left hyper-deviation was identified in 1 healthy participant on OCT measuring 2.26° (~ 3.95Δ). This participant did not have a vertical latent deviation on distance APCT, but did have a left hyperphoria measuring 5Δ on near APCT. A weak correlation was observed between APCT and OCT measurements for horizontal deviation in this group (Pearson's r=0.06, P=0.830, CI 0.14-0.85).

Discussion

In this paper we explore OCT-derived quantification and assessment of strabismus angle using a novel prototype binocular OCT system.

The device was able to correctly identify the direction of the deviation in the strabismus group, including both horizontal and vertical elements. The device also indicated a vertical deviation (<4Δ) in three participants who were recorded as vertically orthophoric. Small deviations (<2Δ), particularly vertical deviations, may not be reliably perceived by the unaided eye on cover testing[11, 12] but may be visible on the OCT. The binocular OCT identified a horizontal deviation in 12 participants of the healthy cohort. In 9 of these participants, the direction of the deviation on OCT was the same as the latent deviation found on APCT. This suggests that the binocular OCT is measuring both manifest and latent components.

In horizontal misalignment, the agreement between the methods tended to decrease as the size of the deviation increased. A similar heteroscedastic pattern was found for vertical misalignments however our sample was skewed towards smaller deviations. The LoA were larger than the inter-examiner variability found by de Jongh et al.[13] for horizontal deviations (10Δ). This would suggest that our method is not in strong agreement with APCT. However, a larger sample is required to confirm inferences from Bland-Altman plots. Differences between the methods may be partly attributable to the limited scale of prism diopters - as the deviation becomes larger, the difference in degrees between each prism diopter also increases. In addition, increments between diopters in prism bars increase as the power increases. For example, between 1-10Δ, prism power increases in increments of 1 diopter, whereas between 20-50Δ, power increases by 5Δ increments, forcing the orthoptist to choose the closest prism that neutralises the misalignment. Whereas, the binocular OCT is able to measure strabismus angle more precisely using a scale of degrees instead of diopters. A longitudinal and repeatability study is required to validate this method and to investigate whether OCT-derived measurements are valuable for monitoring the change in size of misalignment over time.

There are several limitations of the device at present, however it is likely that these can be overcome in future iterations. A significant limitation of the device includes the inability to ascertain whether a heterophoria or heterotropia is present. We observed deviations in both the healthy and strabismus cohorts. It is likely that the device is reliably identifying manifest vertical and horizontal components in the strabismus group. However, if the device was used as a screening device for manifest strabismus, it may have a high false positive rate particularly for horizontal deviations as observed in the healthy cohort. The unique features of the binocular OCT could potentially be extended to perform a cover test by switching the fixation between the eyes to differentiate between these entities. In the present study, all strabismus participants had a constant deviation. Those with intermittent deviations may not be identified using the current prototype setup. Real-time video OCT with 3D-rendering would also aid measurement of torsional deviations. By bringing the fixation target closer to the eyes, the device has the capacity to simulate near fixation to measure deviation at various distances. In addition, the current prototype setup performs ocular motility testing by displaying the fixation target at different locations of the screen.[7] Strabismus with varying gaze or motion, in addition to alternating fixation, may help discern between primary and secondary deviations in incomitant strabismus.

The prototype currently corrects a mean spherical equivalent of the user's habitual correction to aid visualization of the fixation target. Refractive error can affect the size of the deviation, and the inability to correct cylindrical error may contribute to the differences observed between the methods. Additionally, although the device simulates distance fixation, proximal convergence may attribute to differences between APCT and OCT measurements. In one exophoric participant, a significant eso-deviation was found on OCT. Monocular viewing conditions has been shown to cause accommodative convergence which may affect these results.[14] In subsequent devices with binocular viewing conditions this may be reduced. Some users of the device may naturally fixate closer than distance fixation, and this could explain the larger exo-deviations found on OCT compared to APCT in the healthy cohort. This may also explain the vertical component found in the one healthy participant who had a vertical deviation at near.

Our method of using the pupil margin as a reference plane for tilt may contribute to error. An anatomical landmark such as Schwalbe's line may be less variable as this cannot change dynamically like the iris, but may be less discernible, particularly in vertical scans due to occlusion of this landmark by the eyelids. Visual axis data could potentially provide more accurate measurements of strabismus. This could be determined by using retinal OCT images of the fovea that are also acquired using the device. The device currently does not measure axial length which prevents mapping the retinal and anterior segment images to each other to determine the visual axis. However, if axial length data could be obtained, the visual axis could potentially provide a reliable method of measuring strabismus using OCT, particularly in strabismus with normal retinal correspondence.

In summary, we present a novel application of OCT imaging to detect and measure ocular misalignment. The advantage of this method is the ability to detect subtle differences in the size of strabismus that may not be visible to the naked eye. This is encompassed within a device that can perform several functional tests in addition to whole-eye imaging. The automated manner of the device means a highly skilled specialist is not required to take measurements of the deviation, therefore making it ideal for screening purposes. As discussed, measuring strabismus using prism bars has limitations particularly at larger angles. The binocular OCT can provide a more precise measurement of this angle using degrees (with out without converting back to prism diopters). This may be useful for measuring strabismus over time, before and after surgery, or for patients undergoing botulinum toxin injections. Although the current setup has many caveats, future iterations of the binocular OCT may allow quicker and more accurate assessments of strabismus particularly where orthoptists are limited with huge patient volumes. In addition, the device can output objective quantitative data for ocular misalignments as well as for other diagnostic tests,[7] aiding the diagnosis and monitoring of eye disease.

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Author Contributions:

R.C., P.J.M., R.S.A., P.A.K. were involved in the study setup

R.C., V.K.T. collected the data for the study

R.C. analysed the data

R.C., P.J.M., V.K.T., R.S.A., P.A.K. wrote the manuscript

Access to data:

R.C. had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

References

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1. Graham PA. Epidemiology of strabismus. *Br J Ophthalmol.* 1974;58(3):224-231.
2. Stidwill D. Epidemiology of strabismus. *Ophthalmic and Physiological Optics.* 1997;17(6):536-539.
3. Pediatric Eye Disease Investigator Group. Interobserver reliability of the prism and alternate cover test in children with esotropia. *Arch Ophthalmol.* 2009;127(1):59-65.
4. Johns HA, Manny RE, Fern K, Hu Y. The Intraexaminer and Interexaminer Repeatability of the Alternate Cover Test Using Different Prism Neutralization Endpoints. *Optometry and Vision Science.* 2004;81(12):939-946.
5. Weber KP, Rappoport D, Dysli M, et al. Strabismus Measurements with Novel Video Goggles. *Ophthalmology.* 2017.
6. *gazelab*. Available at: http://www.bcninnova.com/gazelab. Accessed October 18, 2017.
7. Chopra R, Mulholland PJ, Dubis AM, et al. Human factor and usability testing of a binocular optical coherence tomography system. *Trans Vis Sci Tech.* 2017;6(4):16
8. Li Y, Shekhar R, Huang D. Corneal pachymetry mapping with high-speed optical coherence tomography. *Ophthalmology.* 2006;113(5):792-799 e792.
9. Irsch K. Optical Issues in Measuring Strabismus. *Middle East Afr J Ophthalmol.* 2015;22(3):265-270
10. Bland, JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet (London, England)*. 1986;1(8476):307–310.
11. Ludvigh E. Amount of eye movement objectively perceptible to the unaided eye. *Am. J. Ophthalmol.* 1949;32:649-50.
12. Romano PE, von Noorden, GK. Limitations of cover test in detecting strabismus. *Am. J. Ophthalmol.* 1971;72:10-12.

13. de Jongh E, Leach C, Tjon-Fo-Sang MJ, Bjerre A. Inter-examiner variability and agreement of the alternate prism cover test (APCT) measurements of strabismus performed by 4 examiners. *Strabismus*. 2014;22(4):158-166.

14. Chirre E, Prieto P, Artal P. Dynamics of the near response under natural viewing conditions with an open-view sensor. *Biomed Opt Express.* 2015;6(10):4200

Table

Table 1. Orthoptic assessment and binocular optical coherence tomography measurements for fifteen participants with strabismus. Vertical deviation measurements obtained using OCT are indicated as hyper- or hypo- with respect to the strabismic eye (i.e. the eye with a horizontal deviation if present).

Participant	Clinical diagnosis	Binocular status in primary position	Age	Visual acuity (logMAR)		Mean spherical equivalent (both eyes) (DS)	Distance prism cover test (6 metres)	Prism cover test - equivalent angle in degrees		Angle measured on OCT (degrees)		OCT angle converted to prism (rounded to nearest diopter)
				Right	Left			Horizontal	Vertical	Horizontal	Vertical	
1	RE consecutive exotropia (prior strabismus surgery for childhood esotropia)	No diplopia, RE suppression	35	0.60	0.00	0 (unaided)	12ΔBI 5ΔBD R/L	6.84	2.86	6.14 (exo)	11.13 (RE hyper)	11ΔBI 20ΔBD R/L
2	LE/Alternating esotropia (Duane's syndrome)	No diplopia, LE suppression	24	-0.10	-0.10	-0.63	45ΔBO	24.23		18.67 (eso)	2.23 (LE hyper)	34ΔBO 4ΔBD L/R
3	RE fully accommodative esotropia	No diplopia, binocular	23	0.62	0.02	+2.88	6ΔBO 4ΔBD R/L	3.43	2.29	6.17 (eso)	4.87 (RE hyper)	11ΔBO 9ΔBD R/L

		single vision										
4	RE consecutive exotropia (prior strabismus surgery for childhood esotropia)	No diplopia, RE suppression	63	0.00	0.16	+5.38	45ΔBI 3ΔBD R/L	24.23	1.72	29.34 (exo)	2.93 (RE hyper)	56ΔBI 5Δ R/L
5	RE consecutive exotropia (prior strabismus surgery for childhood esotropia)	No diplopia, RE suppression	50	0.18	-0.02	-0.06	25ΔBI	14.04		19.83 (exo)	2.28 (RE hypo)	36ΔBI 4ΔBD L/R
6	LE childhood esotropia	No diplopia, LE suppression	47	0.16	0.76	-2.44	25ΔBO	14.04		11.08 (eso)	0.00	20ΔBO
7	LE longstanding distance esotropia	Diplopia	74	0.00	0.00	-1.25	14ΔBO 4ΔBD L/R	7.97	2.29	12.96 (eso)	2.18 (LE hyper)	23ΔBO 4ΔBD L/R
8	LE myopic esotropia	Diplopia	74	-0.10	0.00	-0.5	25ΔBO 2ΔBD R/L	14.04	1.15	23.74 (eso)	3.48 (LE hypo)	44ΔBO 6ΔBD R/L
9	LE hypertropia (secondary to thyroid eye disease)	Diplopia	62	-0.10	0.00	+1.25	20ΔBD L/R		11.31	0.00 (ortho)	18.15 (LE hyper)	33ΔBD L/R

10	RE residual esotropia with hypertropia (prior strabismus surgery for childhood esotropia)	No diplopia, RE suppress ion	31	-0.08	-0.12	+3.13	14ΔBO 5ΔBD R/L	7.97	2.86	2.07 (eso)	5.89 (RE hyper)	4ΔBO 10ΔBD R/L
11	RE exotropia with hypertropia (decompensated after loss of vision from a right retinal detachment)	Diplopia	31	0.78	-0.20	0 (unaided)	45ΔBI 3ΔBD R/L	24.23	2.29	16.97 (exo)	2.02 (RE hyper)	31ΔBI 4ΔBD R/L
12	LE exotropia with hypotropia (secondary to left sphenoid wing meningioma)	Diplopia	74	-0.04	0.30	+1.25	20ΔBI 25ΔBD R/L	11.31	14.04	14.75 (exo)	14.26 (LE hypo)	26ΔBI 25ΔBD R/L
13	LE residual exotropia (prior strabismus surgery for childhood exotropia)	No diplopia, LE suppress ion	55	0.00	0.48	0 (unaided)	60ΔBI 6ΔBD R/L	30.96	3.43	26.33 (exo)	6.30 (LE hypo)	49ΔBI 11ΔBD R/L
14	RE age-related distance esotropia	Diplopia	68	0.16	0.00	-1.50	6ΔBO	3.43		1.33 (eso)	0.00	2ΔBO
15	LE myopic esotropia (and glaucoma)	Diplopia	61	-0.10	0.10	-0.25	16ΔBO	9.09		10.99 (eso)	1.54 (LE hyper)	19ΔBO 3ΔBD L/R

Figures and Figure Legends

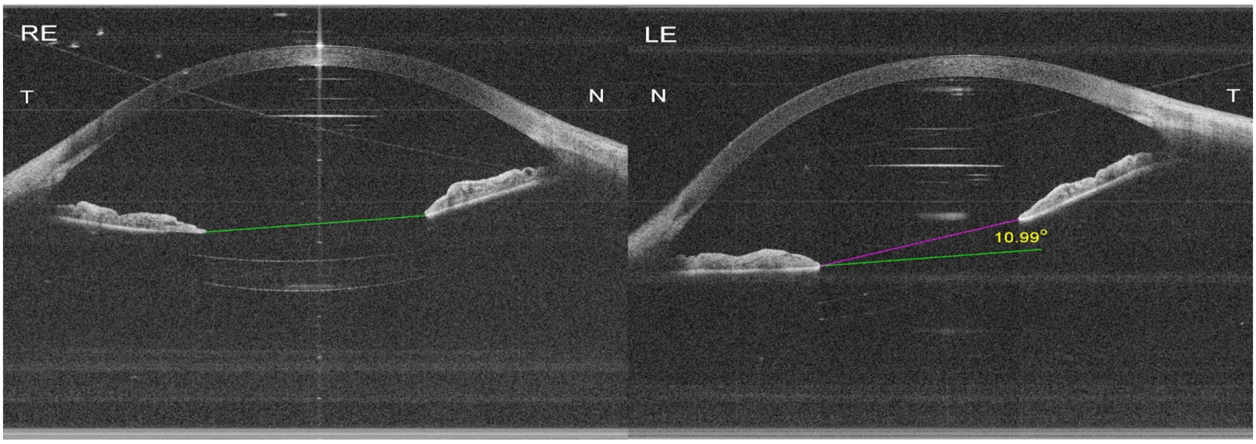

Figure 1.

Title: Simultaneously acquired pair of anterior segment optical coherence tomography (OCT) images obtained for Participant 15.

Caption: The right eye is the fixating eye, and the left eye is the strabismic eye. The angle of the deviation is calculated by measuring the tilt of the eye with respect to the fixating eye. The pupil margins are used as landmarks to measure tilt. This pair of images indicate a left esotropia. (N = nasal, T = temporal)

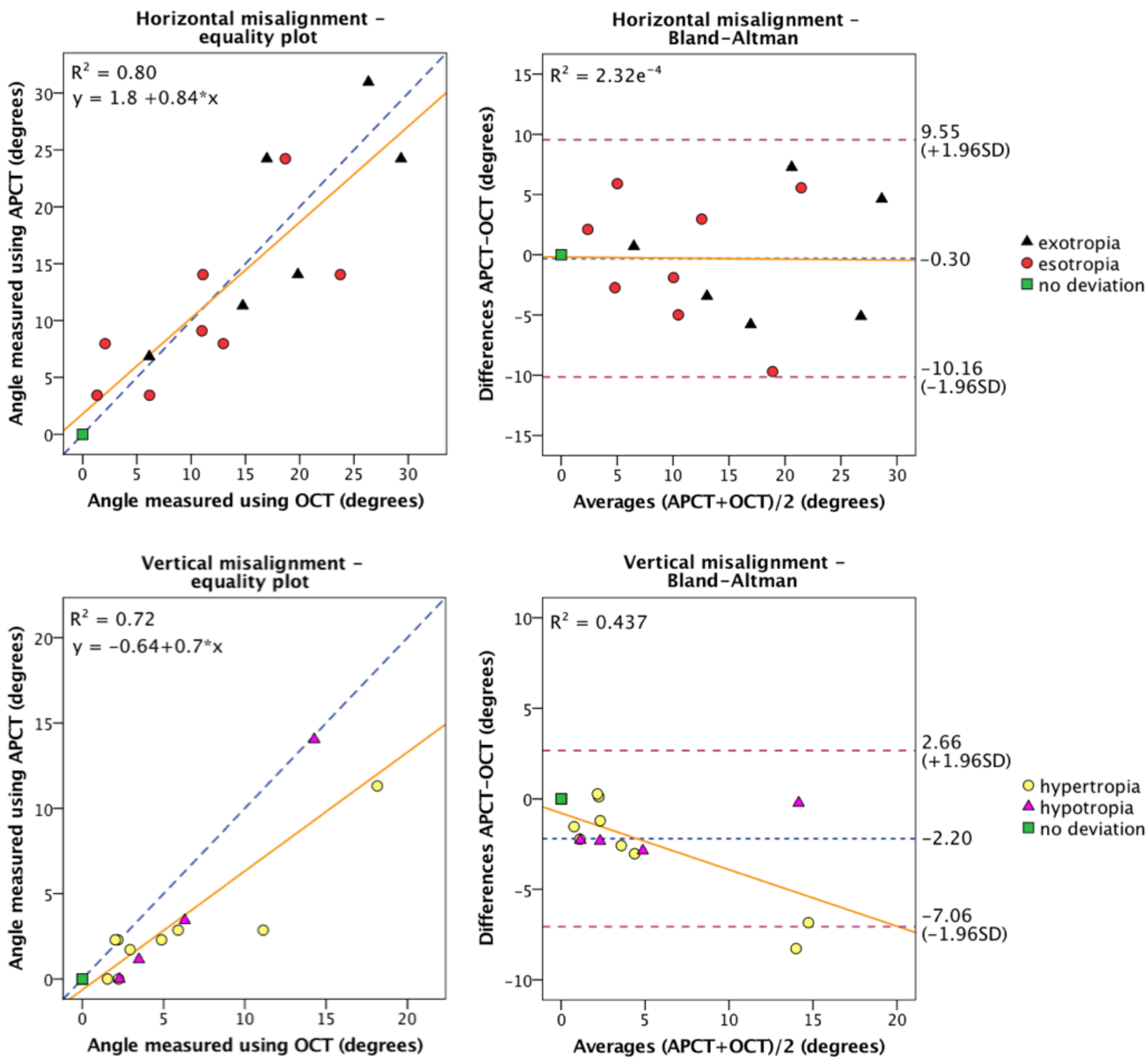

Figure 2.

Title: Equality and Bland-Altman plots comparing agreement of measurements obtained using APCT and binocular OCT.

Caption: Measurements for horizontal misalignments vertical misalignment are presented in the top and bottom plots respectively. For vertical deviations, pink triangle markers represent a hypo- deviation with respect to the strabismic eye. Green indicates no measured deviation with either method. Regression lines are represented in orange. For the equality plots the dashed line represents perfect agreement. The reference lines on the Bland-Altman plots show the mean and 95% limits of agreement (LoA). The LoA were ±9.85◦ from the mean for horizontal misalignments, and ±4.86◦ for vertical misalignments.