Automated Diagnosis and Measurement of Strabismus in Children

OREN YEHEZKEL, MICHAEL BELKIN, AND TAMARA WYGNANSKI-JAFFE

• PURPOSE: **Manual measurements of strabismus are subjective, time consuming, difficult to perform in babies, toddlers, and young children, and rely on the examiner's skill and experience. An automated system, based on eye tracking and dedicated full occlusion glasses, was developed to provide a fast, objective, and easy-to-use alternative to the manual measurements of strabismus. This study tested the efficacy of the system in determining the presence of strabismus in children, as well as its type and the amount of deviation, in addition to differentiating between phorias and tropias.**

• DESIGN: **A prospective, masked, inter-rater reliability study.**

• METHODS: **A prospective, masked, cross-sectional study included 69 children, 3-15 years of age. A cover-uncover test and a prism alternating cover test (PACT) for the primary gaze, at a distance of 50 cm, were performed by 2 independent, masked examiners and by the automated system.**

• RESULTS: **A high correlation was found between the automated and the manual test results ($R = 0.9$ and $P < 0.001$ for the horizontal deviation, and $R = 0.91$ and $P < 0.001$ for the vertical deviations, with 100% correct identification of the type of deviation). The average automated test duration was 46 seconds. The Bland-Altman plot, used to compare the 2 measurement methods, showed a mean value of −2.9 prism diopters (PD) and a half-width of the 95% limit of agreement of ±11.4 PD.**

• CONCLUSION: **The automated system provides precise detection and measurements of ocular misalignment and differentiated between phorias and tropias. It can be used in participants from the ages of 3 years old and up.** (Am J Ophthalmol 2020;213:226–234. © 2019 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).)

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From NovaSight Ltd. (O.Y.), Airport City; Goldschleger Eye Research Institute (M.B.), Sheba Medical Center, Tel Hashomer; Sackler Faculty of Medicine (M.B., T.W-J.), Tel Aviv University, Tel Aviv; and Sheba Medical Center; Goldschleger Eye Institute (T.W-J.), Tel Hashomer, Israel.

Inquiries to: Tamara Wygnanski-Jaffe, Goldschleger Eye Institute, Sheba Medical Center, Tel Hashomer, 52521, Israel; e-mail: Tamara.Wygnanski@sheba.health.gov.il

MEASURING THE TYPE AND MAGNITUDE OF ocular misalignment is essential for diagnosing strabismus, determining treatment, and following up.[1] The conventional method for detecting the presence of manifest strabismus is the cover-uncover test (CUT). In addition, the conventional method for measuring the total ocular deviation, combining manifest and latent deviations when present, is the prism alternating cover test (PACT).[2–6] The PACT's disadvantages include its long test duration, the difficulty in performing the test in young, uncooperative children, and the test's dependence on the examiner's training, skill, and experience. Consequently, this test is subject to high interexaminer variability.[7–10]

In order to develop standardization and reduce the variability of manual measurements, attempts were made to develop objective automated strabismus measurement devices. These include automated image analysis software,[11] videos based on infrared eye tracking,[12] video goggles to perform a Hess screen test,[13] and binocular optical coherence tomography.[14] Although good agreement between the newly proposed technologies and the PACT measurements was reported, some technologies are limited by the inability to incorporate spectacles with refractive error correction and others by the inability to block vision in all gaze positions or because the participants' cooperation is required; therefore, these technologies are unsuitable for use in young children. None of the proposed methods could identify and differentiate between phorias or latent eye deviations and tropias or manifest eye deviations. An eye tracker can precisely detect saccadic eye movements, gaze position, fixation stability, smooth pursuit eye movements, nystagmus, and alignment of the visual axis.[15] Recently, a strabismus diagnosing system, based on eye tracking, was developed; however, it is only able to detect the direction of the strabismus without quantifying the amount of the deviation.[12] This system also requires a pretest calibration process, making it unsuitable for young children and patients who are otherwise unable to undergo the conventional sensorimotor examination.

The system described here is a newly developed objective eye–tracking-based device that can automatically detect the deviating eye and assess the extent and direction of both heterophorias and heterotropias. This study compared the performance of this eye–tracking-based test to those of the manual CUT and PACT methods.

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SUBJECTS AND METHODS

PARTICIPANTS WERE PROSPECTIVELY RECRUITED FROM THE Goldschleger Eye Institute at the Sheba Medical Center, Israel (clinical trials government identifier MOH 2018-01-09001991). The study was approved by the Institutional Review Board of the Sheba Medical Center, Israel, and written informed consent was obtained from all guardians. The study adhered to the ethical standards established by the Declaration of Helsinki for research involving human participants. Participants were consecutively recruited from the hospital clinic, according to their appointment schedule, with no prior selection, until the required sample size was obtained. All participants were screened by a pediatric ophthalmologist before they entered the trial. Participants were excluded if they did not match the inclusion criteria, they were unable to cooperate, had low vision (≤20/200), or had abnormal anterior segment configuration.

The testing distance of 50 cm was carefully controlled during both the automatic and the manual tests. The automated testing distance was monitored constantly using 2 parallel and independent methods. The first method uses the eye tracker's ability to measure the distance of the eyes from the eye tracker camera positioned on the screen. The second method uses the designated marks on the full-occlusion glasses that are part of the testing system; this also enables accurate measurement of their distance from the monitor. In addition, the operator's screen indicates any change in the patient's position. The orthoptists were instructed to carefully monitor the testing distance throughout the test, using a 50-cm tape.

• **MANUAL EXAMINATION PROCEDURE:** All participants underwent complete ocular assessment, orthoptic assessment, and automated testing. All tests were performed with the participants fixating on accommodative targets at 50 cm, using their habitual optical correction. Two examiners (either 2 independent orthoptists or a pediatric ophthalmologist and an orthoptist) performed the manual CUT and PACT on each participant. Both examiners were masked to the results of the other examiner and to the automatic test results. The two manual examinations and the automated tests were performed during the same visit.

• **AUTOMATED EXAMINATION PROCEDURE:** Automatic testing was performed twice by using the EyeSwift system (NovaSight Ltd., Airport City, Israel). This system is based on eye tracking technology that provides continuous information for the gaze position of each eye. Near-infrared illumination is used to create reflection patterns from the cornea (glint) and pupil reflection; these reflections are detected by capturing images using an infrared camera. Following detection, a vector formed by the angle between the cornea and the pupil reflections is calculated. Image processing algorithms are then used to estimate the position of the eye and the point of gaze.

To perform the automated deviation measurement procedure, a dedicated pair of wireless glasses, controlled by the system, was used to enable each eye to be covered separately. The participant wore the wireless glasses over prescription glasses, if required, and followed a visually stimulating target, presented on the screen, simultaneously with audio augmentation. No language or verbal skills were required. The first step in the procedure was to use an automated CUT to assess the presence of a tropia and, if present, to determine the deviating eye and the amount of the deviation. The second step was to use an automated ACT to measure the amount of total deviation and its direction, similarly to the manual PACT but without the physical presence of a prism. If a tropia was detected using CUT, the deviating eye was reported (i.e., right, left, or alternating). If a deviation was detected using only ACT and not CUT, a phoria was reported, including the deviation direction (i.e., esophoria, exophoria, hyperphoria, or hypophoria). In addition, if the ACT began with no tropia but a phoria developed during ACT and, by the end of ACT, under binocular viewing conditions, a tropia was measured, an intermittent deviation was reported. Once the test was completed, the numerical and graphical results of the deviation type, direction, and magnitude were recorded.

• **EYE-TRACKER SYSTEM:** The eye–tracker-based system includes the following components. 1) Tablet PC (Microsoft, Redmond, Washington): Lenovo IdeaCenter AIO 520-24IKL (60-Hz refresh rate with a resolution of 1,920 × 1,080 pixels) used for displaying targets, running the software, and for data storage. 2) Tobii with a sampling rate of 90 Hz; EyeTracker 4C, Mississauga, Ontario, Canada. 3) Test controller: it displays the graphic user interface, performs the test, and presents the test results. 4) Occlusion glasses: these glasses occlude the vision of a participant's eyes in order to simulate manual occluding, as used in CUT and PACT. 5) Glasses controller: it allows the wireless flow of information between the software and the glasses. The controller opens or occludes each lens according to the software commands. 6) Testing distance: the eye tracker image measures the distance between the eye tracker and the subject.

During the automated procedure (Supplemental Figure 1), a fixation target was presented to confirm that the participant was observing the screen. The target dimensions were 1.2 × 1.6 cm (Supplemental Figure 2). For the automated CUT, a short animated movie, with dimensions 1.9 × 2.2 cm, containing accommodative fine details, was presented (Supplemental Video 1). The test began with binocular viewing of the target (Supplemental Video 2). Once the first eye was covered, the algorithm searched for a movement in the noncovered eye, such a movement

TABLE. Participant Characteristics

Eye-Tracking-Based Test Horizontal Deviation (PD)	APCT Horizontal Deviation (PD)	Eye-Tracking-Based Test Vertical Deviation (PD)	APCT Vertical Deviation (PD)	Right Eye Prescription (D)	Left Eye Prescription (D)	Age, y
Ortho deviation						
<4	<4			0	0	7
<4	<4			0.00 to 1.00 × 105	+0.50 to 1.25 × 60	6.5
<4	<4			+2.00 to 1.50 × 90	0	6.5
<4	<4			0	0	5.5
<4	<4			+0.50	+0.50	12
<4	4.5			+0.50	+0.50	11
<4	6			0	0	4.5
<4	<4			0	0	8.5
Exo deviation						
<4	<4			0	+1.00 to 1.00 × 85	3
<4	<4	6	13	−0.75	−0.75 to 2.00 × 175	9.5
<4	<4			−8.50 to 3.00 × 155	−11.50 to 3.50 × 25	9.5
<4	<4	<4	5	0	0	3.5
<4	<4			0	0	3.4
<4	7			0	0	5
5	0			0	0	14
5	0			0	0	9
7	10			0	0	14
7	10			0	0	8.5
8	0			0	0	3
8	0			−1.00 to 1.00 × 80	−1.00 to 1.00 × 95	14
9	0			+4.25 to 1.75 × 11	+0.25 to 0.50 × 180	11
9	0			0	0	8
11	6			−7.00	−2.00	11.5
11	8			0.00 to 1.00 × 23	−3.00 to 0.75 × 8	6
11	17			+1.00 to 1.75 × 178	+2.00 to 3.00 × 8	6
13	17			0	0	7
13	8			0	0	6.5
13	14			−1.75 to 0.50 × 160	−0.75 to 0.50 × 177	7.5
13	18			0	0	7.8
14	12			0	0	3
16	18			0	0	5.5
16	10	<4	5	+0.25 to 0.50 × 70	+0.75 to 0.50 × 70	9
18	24			−1.00	−1.00	8.5
19	16			−0.50	−0.50	6
20	18			+0.75 to 0.75 × 180	+0.75 to 0.75 × 30	9.5
20	17			0	0.25	11
20	20			0	0	7
23	30			+0.75 to 0.75 × 176	+0.75 to 0.75 × 176	9.5
27	21			0	0	6
30	25			0	0	8.5
31	31	<4	5	+1.25 to 0.75 × 90	+0.75 to 0.50 × 70	15
34	30			+0.50	+1.00 to 0.50 × 90	10
44	25			0.00 to 2.00 × 13	0.00 to 2.75 × 167	4.5
50	38			0	0	5
Esotropic deviation						
<4	<4	7.5	6.5	+3.25	+4.50	6
5	0			+2.50 to 1.75 × 3	+3.00 to 2.00 × 180	10
5	11			+3.00	+3.00	7
8	6.5			0	0	7.5
8	9			+0.50	+1.75 to 1.00 × 2	7

Continued on next page

TABLE. Participant Characteristics (*Continued*)

Eye-Tracking-Based Test Horizontal Deviation (PD)	APCT Horizontal Deviation (PD)	Eye-Tracking-Based Test Vertical Deviation (PD)	APCT Vertical Deviation (PD)	Right Eye Prescription (D)	Left Eye Prescription (D)	Age, y
9	8			+4.00 to 4.00 × 173	+3.00 to 2.75 × 5	8
11	8			+6.50	+7.00	3
11	13	8	14	0	0	5.5
12	10			+2.50	+2.50	11.5
13	6			+1.00 to 0.75 × 175	+1.00 to 0.75 × 10	8
14	18			0	0	5.5
17	10			+2.75 to 1.00 × 180	+1.75 to 1.00 × 5	6.5
20	12			0	0	4
20	16			0	0	8
22	10	10	19	+2.00 to 1.25 × 159	+2.25 to 1.50 × 13	8
23	21			0	0	6
23	19			+1.00 to 1.50 × 180	+1.00	3.5
23	18	<4	6	0	0	5
27	30			0	−0.25 to 1.25 × 5	5.5
28	30			+5.75	+6.00	6
30	25			0	0	8.5
35	40			−1.00	−0.50	13
44	39			0	0	4.5
49	43			0	0	6.5
50	31			+0.25 to 0.50 × 162	−0.50 to 2.00 × 23	3.4

APCT = alternate prism cover test; D = diopters; Eso = esodeviation; Exo = exodeviation; Ortho = orthophoria; PD = prism diopters.
Eye deviation metrics, stereo acuity (arc seconds), and demographics are listed for each patient. The first column represents the average of the 2 measurements of the automated system. The second column represents the average of the 2 manual measurements in PD.

indicated the presence of a tropia. The procedure was then repeated for the fellow eye. For the automated ACT, 1 eye was covered at a time, and the algorithm searched for a change in the fixation position of the noncovered eye. The eyes were alternately covered for 3 seconds at a time, for a total of 30 seconds (i.e., repeated in 5 cycles), with no binocular viewing allowed between alternations. The resulting deviation between the eyes was recorded continuously. Next, the maximal deviation between the gaze positions of the 2 eyes was calculated and used to shift the position of the monocular targets accordingly. The procedure was then repeated until no eye movement was detected. Finally, the precise amount of the deviation was calculated using the ratio of the maximal distance between the 2 monocular targets on the monitor and the sitting distance. The test duration depended on the ability of the participant to fixate to allow a sufficient amount of data to be collected. The algorithm of the automated test is designed to identify fixation within a predefined region of interest in order to confirm that the participant is looking at the target with at least 1 eye. The measurement trial automatically pauses if the participant is not focusing within the target region of interest and automatically continues once refixation occurs. In addition, the operator may observe the eye gaze position, which is continuously presented on the operator's monitor throughout the test.

All tests were performed at a distance of 50 cm in the primary gaze position. Owing to the Eye Tracker's accuracy of 1.00 prism dioptr (PD) and the target size presented on the monitor, it is possible to detect artifact deviations in the range of 4 PD and below. In order to avoid reporting artifacts in deviation measurements, eye deviations of 4 PD and above are reported, and smaller deviations are regarded as artifacts. The first manual test was used to determine whether the participant meets the inclusion criteria. The order of the subsequent tests, that is, the second manual test and the automated test, were randomized to eliminate any bias in the results, such as fatigue.

• **OUTCOME MEASUREMENTS:** Interexaminer variability was calculated for the manual PACT and automated ACT. Test-retest reliability and Pearson correlation coefficients between the angles of deviation measured by the different methods were analyzed.

• **STATISTICAL ANALYSIS:** Agreement between the manual and automated tests was represented in Bland-Altman plots and concordance correlation coefficients. Pearson correlation coefficient was obtained to measure the strength of the linear relationship between each test. *P* values of <0.05 were considered statistically significant. A 2-way ANOVA was performed for group comparisons.

RESULTS

SEVENTY-TWO SUBJECTS WERE PROSPECTIVELY RECRUITED from the Goldschleger Eye Institute at the Sheba Medical Center, Israel. Three patients were excluded from the study due to their inability to complete the test, mistaken instillation of cycloplegic eye drops prior to the test, or their inability to fixate, inability to cooperate due to many factors including developmental delay, or were diagnosed with mental health issues (Table). Sixty-nine eligible participants were included, 3-15 years of age (mean 7.17 ± 2.78 SD years of age). The participants had either congenital or acquired forms of manifest or latent strabismus or no deviation. Twenty-five had an esodeviation, 36 had an exodeviation, 8 were orthophoric, and 8 exhibited a vertical deviation.

In the first step, manual and automated CUT results were compared. Nineteen participants had constant tropia, 15 had intermittent tropia, and 35 had no tropia (orthotropia). One patient exhibited no eye movements during the automated CUT and was diagnosed as orthophoric, in contrast to the manual CUT, which detected a tropia.

Interexaminer variability for the manual PACT results was tested. The Bland-Altman plot showed consistent variability across the graph. The mean value was 1.6 PD, and the half-width of the 95% limit of agreement was ±12.0 PD (Figure 1A). There was no overall tendency for the values of one examiner to be higher or lower than the values of the other.

• **HORIZONTAL DEVIATION:** The PACT and automated ACT results showed a highly significant positive correlation (R = 0.9; $P < 0.002$) (Figure 2). The Bland-Altman plot, comparing the 2 measurement methods, is presented in Figure 1B. The mean value was −2.9 PD, and the half-width of the 95% limit of agreement was ±11.4 PD. Comparison of the results showed no significant differences between the outcomes of the 2 tests $F_{(1,272)} = 3.18$; $P = 0.07$ for the test effect; $F_{(1,272)} = 0.33$; $P = 0.56$ for the repetition effect; $F_{(1,272)} = 0.65$; $P = 0.65$ for the test × repetition interaction). Interdevice variability for the automated ACT results was tested. The Bland-Altman plot showed consistent variability across the graph. The mean value was 0.2 PD, and the half-width of the 95% limit of agreement was ±4.25 PD (Figure 1A). There was no overall tendency for the values of one examiner to be higher or lower than the values of the other. Comparison of the SD of the manual PACT and the automated ACT showed that the repeatability of the automated test was significantly higher ($P = 0.008$, paired t-test), with an almost 2-fold reduction in the average SD (11.3 ± 0.5 vs 0.54 ± 0.27, respectively) for the automated ACT vs the manual PACT, respectively.

Moreover, in the youngest subgroup, 3-5 years of age (n = 16; 3.7 ± 0.7 years of age), the PACT and automated ACT also showed a highly significant positive correlation

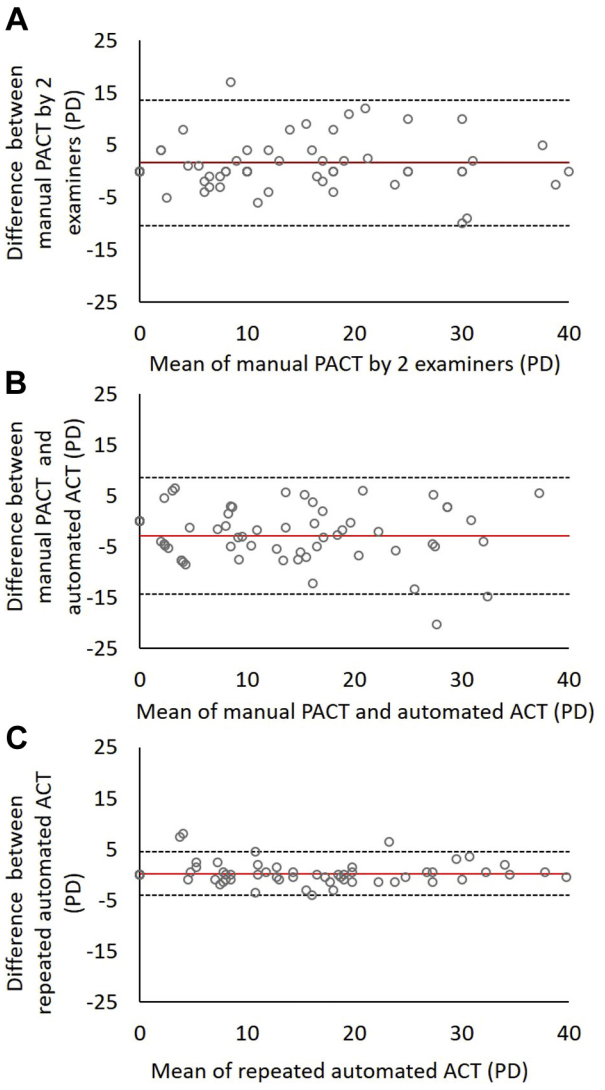

FIGURE 1. Bland-Altman plots. Analysis of the agreement between 2 measurements within each method and between measurements using the 2 methods. (A) The difference between manual PACTs tested by 2 examiners plotted against the examiners' average of manual PACT 2. The upper and lower dotted lines represent the 95% limits of agreement; the solid line shows the mean of the differences. The mean value is 1.6 PD and the half-width of the 95% limit of agreement is ± 12 pris diopters (PD). (B) The difference between the manual PACT and the automated ACT plotted against the mean of the manual PACT and the automated ACT. The upper and lower dotted lines represent the 95% limits of agreement; the solid line represents the mean of the differences. The mean value is −2.9 PD and the half-width of the 95% limit of agreement is ± 11.4. (C) The difference between the repeated automated ACT plotted against the mean of the repeated automated ACT. The upper and lower dotted lines represent the 95% limits of agreement. The solid line represents the mean of the differences. The mean value is 0.2 PD, and the half-width of the 95% limit of agreement is ± 4.25 PD. There is no overall tendency for the values of one test to be higher or lower than the values of the other. ACT = alternating cover test; PACT = prism alternating cover test.

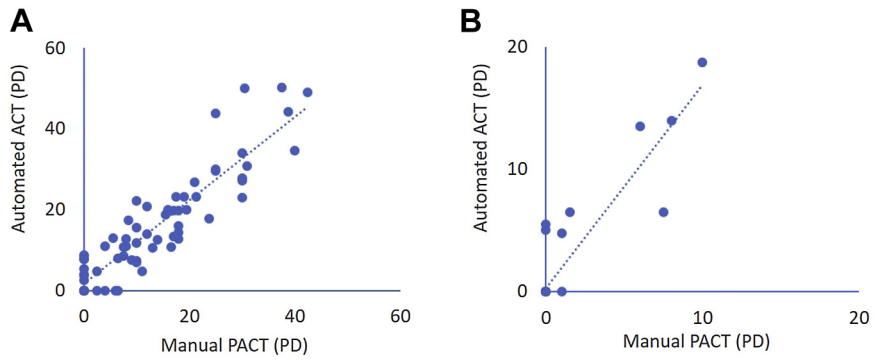

FIGURE 2. Correlation between manual PACT and automated measurements. (A) Horizontal eye deviations as measured by using the automated eye-tracking-based test, individualized to the participant, are plotted against the measurements obtained using the PACT. There is a high correlation between the 2 measurements (correlation coefficient R = 0.9; $P < 0.00001$). (B) Same measurement as in (A) for the vertical eye deviations (correlation coefficient R = 0.9; $P < 0.00001$). PACT = prism alternating cover test.

(R = 0.9; $P < 0.01$), with no significant differences between the outcomes of the 2 tests: $F_{(1,60)} = 1.94$; $P = 0.17$ for the test effect; $F_{(1,60)} = 0.42$; $P = 0.52$ for the repetition effect; $F_{(1,60)} = 0.04$; $P = 0.95$ for the test × repetition interaction.

• **VERTICAL DEVIATION:** In addition to the horizontal deviation, 8 participants exhibited a vertical deviation using the automated ACT and 5 using the manual PACT. One participant, with Brown syndrome, exhibited no vertical deviation with the automated ACT, although a hypodeviation was found using the manual PACT. Another participant exhibited a vertical deviation with the automated ACT, which was not detected by the manual PACT.

There were no significant differences between the outcomes of the PACT measurements performed by the 2 masked examiners: $F_{(1,224)} = 2.94$; $P = 0.08$ for the test effect; $F_{(1,224)} = 0.001$; $P = 0.96$ for the repetition effect; $F_{(1,224)} = 0.01$; $P =$ (0.89 for the test × repetition interaction). Comparison of repeatability showed an almost 2-fold reduction in the SD for the automated test versus the ACPT (0.05 ± 0.03 vs 0.12 ± 0.06, respectively), which did not reach significance due to a large portion of zero vertical deviation ($P = 0.12$, paired *t*-test).

The correlation between the automated and manual tests was 0.9 for esodeviations, 0.88 for exodeviations, and 0.91 for vertical deviations. In orthophoric participants, no deviation was recorded by the automatic system. The average test duration of the automated ACT was 46.00 ± 3.45 seconds (a range of 42-69 seconds).

DISCUSSION

IN THIS STUDY, A NOVEL AUTOMATED SYSTEM FOR measuring ocular misalignment, based on an EyeTracker and a liquid crystal display active shutter glasses, was tested and compared to manual PACT results. The automated system identified the same direction of the deviation as the manual PACT in all cases. The results of the automated ACT showed excellent concordance with those of the PACT for measuring eye deviation in all cases of horizontal and vertical deviations.

Despite the fairly good agreement between the 2 manual examiners in the current study, the PACT relies on subjective interpretation and the examiner's skill in observing very small ocular movements while performing the test.[8] Thus, the accuracy of measurements depends largely on the examiner's expertise and the participant's level of cooperation.[7–10,16,17] Studies showed a significant interexaminer variability in PACT among highly experienced examiners, ranging between 6.9 and 12.5 PD.[18] In this study, the interexaminer variability of the automated test was 4.25 PD, which is much lower than the variability of the manual test, which was 11.95 PD. However, it is noteworthy that the 2 automated measurements were performed consecutively, whereas the manual tests were not necessarily performed consecutively, which may explain the differences in the SDs in favor of the automated test.

Of the 7 cases where the automated system detected an eye deviation, whereas the manual tests showed no eye deviation, in 4 cases at least 1 of the examiners detected an eye deviation, whereas the second examiner reported no eye deviation. Therefore, the average measurement between the 2 examiners indicated an eye deviation below the threshold of 4 PD. In the other 3 cases, the 2 examiners reported no eye deviation, whereas the automated system repeatedly measured a deviation. It is highly unlikely to obtain such repeatable results in the 2 automated measurements when no eye deviation exists (4 and 5, 8 and 8, 9 and 9). Of the 3 cases in which the manual examiners detected an eye deviation and the automated system detected a deviation smaller than 4 PD, in all cases at least 1 of the examiners detected a deviation of 5 PD, which is

very similar to the threshold of 4 PD (5 and 5, 5 and 7, 5 and 8), whereas the automated system detected a deviation of just below the threshold of 4 PD. In one case, 1 of the automated results was just above the threshold (i.e., 4.5 PD), whereas the repeated measurement result was just under the threshold; therefore, their average was lower than the threshold. In the 2 cases of large deviations, a discrepancy existed between the manual and the automated test results; however, the difference between the repeated measurements within each of the tests was small. In the case of a 3.4-year-old participant, the 2 repetitions of automated measurements detected a deviation of 52 and 48 PD versus 26 and 35 PD, respectively, which were detected by the 2 examiners, resulting in an average result of 50 PD in the automated test vs 31 PD in the manual test. This may indicate that the patient had a combination of recurrent esotropia after strabismus surgery, convergence excess, a habitual bifocal prescription, and developmental delay with limited cooperation. In the second case, involving a 4.5-year-old participant, the 2 repetitions of automated measurements detected a deviation of 43 and 44 PD versus 20 and 30 PD, which were detected by the two examiners, resulting in the average results of 44 PD in the automated test versus 25 PD in the manual test. In one case of Brown syndrome, the participant did not exhibit any vertical eye movements during the automatic test, but hypodeviation was detected by the manual PACT. It is possible that this occurred due to an anomalous head posture that the participant adopted during the automated test.

Several objective automated ocular deviation measurement devices have been reported. These include automated image analysis software, video-based infrared eye tracking, video goggles to assess the Hess screen test,[13] and binocular optical coherence tomography to evaluate strabismus in the primary position.[14] Another attempt to estimate the binocular alignment from photographs acquired using a selective wavelength filter and an infrared video camera was also reported.[11] In that system a unique filter was used as an occluder for blocking the participant's view while selectively transmitting the infrared light, followed by analysis of the corneal reflex position, which revealed the latent deviation. Although good agreement with the PACT was reported, this technology is limited by the need for normative ophthalmic biometry. Furthermore, using a nonaccommodative (a spot of light) target and asymmetric kappa angles increased the susceptibility to errors. Another recent pilot trial using a digital video analysis methodology that interprets shadowing related to room light, used for detecting and diagnosing exotropia, was compromised by room light conditions unsuitable for dark eyes.[19] Furthermore, the validity of strabismus testing using video goggles was recently assessed in comparison with the Hess screen test. A high agreement was found between the tests in all tested gaze positions, but both are unsuitable for participants under the age of 6 years (the authors reported that the software and hardware still need refinement).[13] The advantage of this test is that it can be used in patients with visual suppression and who are not suitable for the Hess screen test. It was also reported that binocular anterior segment optical coherence tomography is suitable for measuring the total amount of eye deviation. Importantly, it has the ability to detect subtle differences in the strabismus size that may not be visible to the naked eye; however, it is unable to determine whether the deviation is a phoria or tropia, and only a spherical equivalent can be used for optical correction during the test.[14]

The automated system has several potential advantages compared to the manual PACT. The automated system provides measurements of the latent component of eye deviation; however, this is possible only after disruption of fusion. The test procedure is similar to that of the PACT, but instead of using prisms to shift the target toward the eye's position, the target is shifted on the screen. In addition, the automated system does not require eye tracker calibration, in contrast to the other automated tests, which depend on calibration.[12] Eye Tracker calibration is a process during which the geometric characteristics of a participant's eyes are estimated as the basis for fully customized and accurate gaze point calculation. In the method described here, the Eye Tracker is not directly used for detecting the eye's position but rather for determining whether the eyes move to a target presentation at different locations. The exact deviation is calculated by combining the distance obtained between the 2 monocular targets on the monitor in relation to the sitting distance. Hence, it is suitable for testing participants who have extreme ocular dimensions that deviate from normal variation, such as high refractive errors. The test can be performed with or without optical correction, including spectacles or contact lenses. An additional advantage of the automated system is that the full occlusion glasses allow blockage of the patient's vision but are transparent to the eye tracker; therefore, the gaze position of both eyes can be monitored continuously during the entire test. This noninvasive test provides automatic results that do not require expert operation or interpretation; therefore, these results can potentially be widely implemented in standard clinical practice by technicians having a lower skill level. The automated test takes up to 1 minute to complete, which is advantageous in children and patients with limited levels of cooperation.[20] Moreover, in communities in which strabismus specialists or orthoptists are unavailable, the automated test provides a telemedicine solution for detecting and evaluating strabismus, regardless of the geographical location. The test can be performed by personnel in any clinical setting, and the results can be reported to a remotely located specialist. It is known that the measurement variability of the angle of strabismus may vary over time due to physiological factors, such as fatigue and the patient's anxiety level during the examination.[21] Fast, automated measurements allow for frequently repeated testing, thus improving measurement accuracy

and decreasing the influence of intrapatient errors. Moreover, the algorithm of the automated test is designed to perform 10 repeated measurements in 5 cycles of interchanging right-left eye occlusion, and only once was the vertical deviation consistently detected in all repetitions; with a consistent pattern of the deviating eye movement, it is registered as a vertical deviation. This prevents artifacts of eye movements reported as a vertical deviation. This prevents artifacts of eye movements from being reported as a vertical deviation. An additional benefits of the automated system are that prisms greater than 20 PD are usually available only in step differences of 5 PD, whereas the automated system is suitable for measuring a full range of deviation in steps of 1 PD.

The eye–tracker-based method is based on eye movement detection; therefore, similar to the manual PACT, is it not feasible in patients with extraocular muscle paralysis. For the same reason, this method cannot be applied to patients with a large amplitude of nystagmus, as the system may become misled by the repetitive, uncontrolled eye movements. The automated system reported here was not designed to measure torsion. This study focused on measuring horizontal and vertical eye deviation at 50 cm and in the primary gaze; however, the next version of the system will evaluate eye positions in 9 gaze positions and already includes measurements at 20 feet. The tested prototype version of the device could not distinguish dissociated vertical deviation (DVD) from vertical hypertropia. In the next version, the system will identify cases of monocular and binocular DVD. A limited level of cooperation is required, for example, focusing on an engaging animated target for a test duration of 46 seconds (ranging from 42-69 seconds). Deviations of 4 PD and above were reported. The current results show the possible use of the automated test in children as young as 3 years of age, but further studies with a larger sample in this particular age group are needed.

To conclude, the automated system reported here measures strabismus based on a procedure similar to that of the manual PACT test, while continuously monitoring the gaze position of each eye, and then calculates the distance between the 2 images presented on the screen after eye movements have been completely neutralized. This method may assist in detecting and quantifying eye deviations. It may be used in locations in which skilled eye specialists or orthoptists are unavailable or in settings with a large volume of patients. It can be used before or after surgical or optical treatment, for monitoring patients and for screening purposes. Since the system is entertaining and requires no head constriction, it is suitable for children as young as 3 years of age.

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