A computerized version of the Lancaster red-green test

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PURPOSE	To compare results from a computerized version of the Lancaster red-green test with those of the conventional test.
METHODS	Consecutive adult patients with noncomitant strabismus were tested with the conventional Lancaster red-green test and with a computerized version of the same. The computerized test was administered by means of a 40-inch monitor at a working distance of 50 cm or a projector and screen at a working distance of 1 meter. Agreement between the measured horizontal, vertical, and torsional deviations in the conventional test and both computerized versions was evaluated with the mountain plot, Bland-Altman plot, and Deming regression analysis models.
RESULTS	A total of 82 patients were tested. Agreement of measured horizontal deviation in the conventional test was better with the projector version of the test (limits of agreement: right eye, -4.6^{Δ} to 3.4^{Δ}; left eye, -4.9^{Δ} to 3.5^{Δ}) than the monitor version (limits of agreement: right eye, -10^{Δ} to 4.2^{Δ}; left eye, -8.9^{Δ} to 4.1^{Δ}). The measured vertical and torsional deviation in the conventional test showed good agreement with both versions of the computerized test (limits of agreement $<5^{\Delta}$ for vertical measurements and $<3°$ for torsional measurements). Agreement was similar for right and left eyes.
CONCLUSIONS	The vertical and torsional deviations measured with both computerized versions of the test were in good agreement with those obtained with the conventional test. For measured horizontal deviations, the projector version had better agreement than the monitor version. (J AAPOS 2013;17:197-202)

The Lancaster red-green test[1] is a subjective dissociated test used to measure ocular misalignment in different positions of gaze. Usually the test is performed with the patient wearing red-green goggles and seated 1-2 m in front of a rectilinear grid of black dots drawn on the wall. The patient's response is used to plot the amount of horizontal and vertical misalignment as well as the subjective torsion perceived by the patient in different directions of gaze. In this dissociated test, the patient uses both eyes to participate. Similar dissociated tests include the Hess screen[2] and Lees screen[3]; the latter uses point targets rather than linear streaks and thus cannot measure the subjective torsion in each direction of gaze.

Although the Lancaster red-green test has proved useful in evaluation of patients with incomitant strabismus,

measured deviations may show fluctuations as the result of changes in vergence; the test requires accurate plotting of the patient responses on a paper, a process that may be subject to operator error.[4] In addition, the test requires the use of special flashlights (Foster torches) and a screen or wall with rectilinear grid drawn on it. The aim of this study is to describe a software program based on the same principle as Lancaster red-green test that allows measurement of ocular alignment in different positions of gaze using a computer and a large flat screen monitor or a projector.

Methods

This study was approved by the Cairo University Faculty of Medicine Research Ethics Committee and complied with the tenets of the Declaration of Helsinki. The study enrolled all consecutive adult patients presenting to the ophthalmology clinic and complaining of diplopia caused by noncomitant strabismus during the period from July 2011 to March 2012. The conventional and computerized tests were administered in random order. The computerized version of the test was performed twice, once with the use of a 40-inch monitor and working distance of 50 cm (monitor version) and a second time with a projector and a screen at a working distance of 1 m (projector version).

Conventional Lancaster red-green Test

The conventional test was performed as described by Christoff and Guyton.[5] The patient wore red-green goggles (red filter over the right eye; green, over the left eye) and was seated 1 m from a rectilinear grid of black dots (Figure 1). The distance between each of the two consecutive dots measured 15 cm both vertically and horizontally, subtending an angle of 15^Δ. The patient was given a flashlight (Foster torch) with a green filter, while the examiner held a flashlight with a red filter. Measurements were made with the fixing eye in nine cardinal gaze positions around the perimeter of a square that measured 45^Δ (24°) horizontally and vertically from the center. The examiner shined a red streak vertically on each position. At each position, the patient was first asked if the streak of light presented by the examiner was vertical. If not, the examiner rotated it to the vertical position as perceived by the patient. The patient was then asked to align his green streak with the red streak of the examiner. The test was repeated after replacing the red and green flashlights of the patient and the examiner to measure the deviation with the other eye fixing. The results were charted on a paper with a similar grid by an operator trained in performing the test and masked to the results of the computerized test. The amounts of the vertical and horizontal deviations were measured directly from the wall grid at the time of performing the test to avoid errors during drawing the results. The distance between each two consecutive dots (both vertically and horizontally) corresponds to 15^Δ. By the use of this scale, the horizontal and vertical distances between the center of the red streak (which corresponds to the right eye) and the green streak (which corresponds to the left eye) were converted to prism diopters. The deviation in prism diopters was recorded in the nine diagnostic positions of gaze. Displacements were taken as positive, and those which are out of range were assigned an arbitrary 30. The degree of torsion of each eye was measured directly from the wall grid by a second examiner using a protractor to measure the angle of inclination between the red and green streaks.

Software Program

The program was designed and written in JAVA programming language (Sun Microsystems, Santa Clara, CA), and compiled and run on the Windows platform (Microsoft Corporation, Redmond, WA). The patients wore red-blue goggles (red filter over the right eye, blue filter over the left eye) to test the field of the right eye. The examiner monitored the patient to ensure that the patient's head was straight during the entire examination. The program started by presenting to the patient a red linear target. The patient was asked to rotate the red target using a joystick control until he or she perceived it as vertical (Figure 2). Once perceived as vertical, the patient was asked to press the joystick button and the program then presented to the patient another linear blue target. The patient was asked to move the blue target using the joystick until it is superimposed on the red target. In addition, the patient was asked to rotate the blue target (clockwise or counterclockwise) using the joystick until it was exactly aligned with the red target. Once the patient finished aligning the blue target, he or she was asked to press the joystick button. The computer program then repeated the same steps at another eight
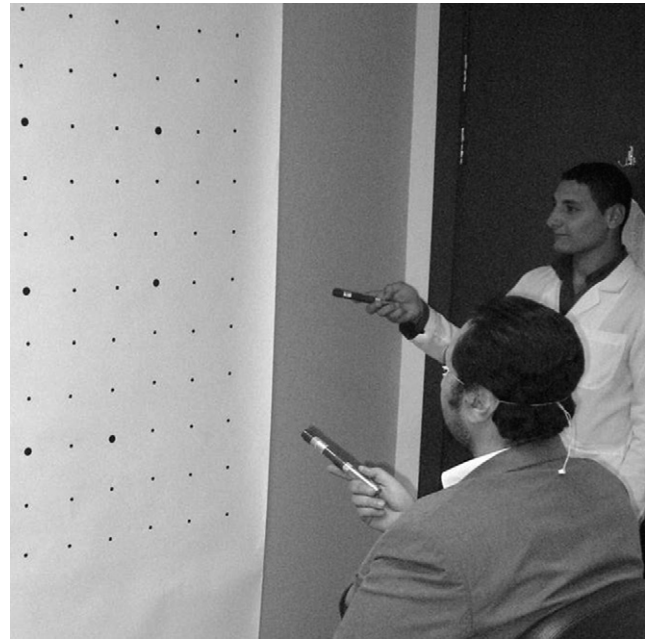

FIG 1. The conventional Lancaster red-green test with a rectilinear grid of black dots drawn on the wall. The subject's eyes are dissociated with red-green goggles. The patient is given a flashlight with a green filter, while the examiner holds a flashlight with a red filter. Measurements are made with the fixing eye in nine cardinal positions around the perimeter of a square that measured 45^Δ (24°) horizontally and vertically from the center.
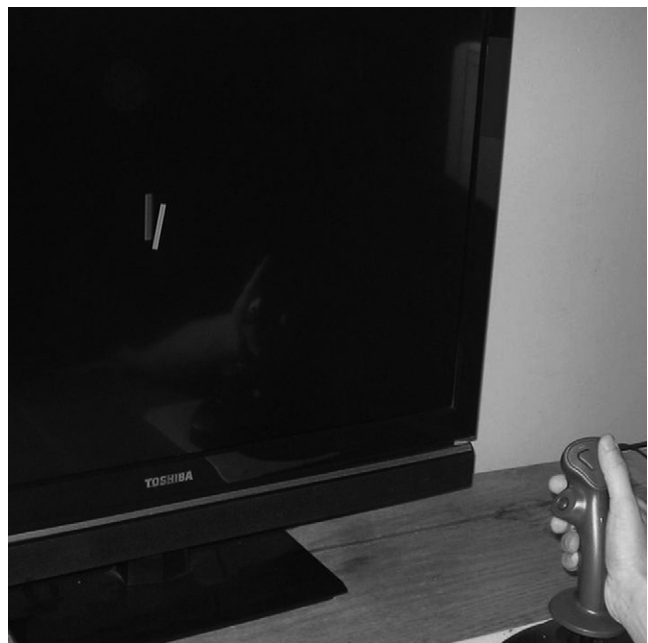

FIG 2. The monitor version of the computerized Lancaster red-green test. The test is performed at a working distance of 50 cm. The subject's eyes are dissociated with red-blue goggles. The patient controls the targets by using a joystick controller.

points corresponding to different positions of gaze. The software program then calculated the amount of horizontal and vertical misalignment as well as the subjective torsion in each position
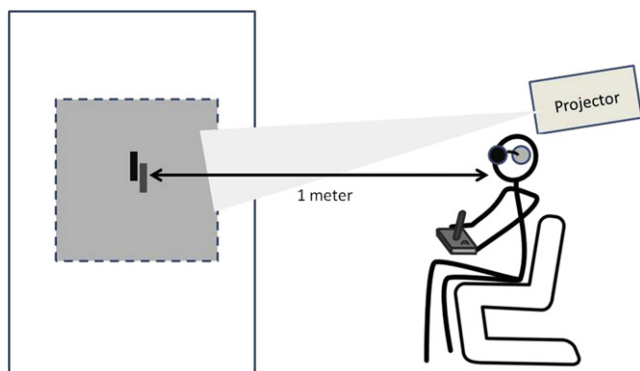
FIG 3. Schematic diagram of the projector version of the computerized Lancaster red-green test. The test is performed at a working distance of 1 meter. The magnification of the projector is adjusted until the projected image becomes aligned with a template screen on the wall. The patient controls the targets using a joystick controller.

of gaze as determined by the working distance and the distance between the red and blue targets. A chart plot displaying the patient's responses and a numerical plot showing the calculated misalignment in different gaze positions were then printed (Figure 3). The test was repeated after replacing the red-blue goggles of the patient to plot the field of the other eye. The test was performed using a 40-inch monitor and a working distance of 50 cm and then repeated using a projector and a working distance of 100 cm with the distance between targets modified to maintain an angle of 45^{Δ} (24°) between each test point and the central point (Figure 4). The magnification of the projector was adjusted until the projected image became aligned with a template screen on the wall. When the image was projected on the template screen, the distance between each of the 2 consecutive test targets was equal to that of the conventional Lancaster red-green test (45 cm). The results of the computerized test were printed out for both versions of the computerized test.

The time taken to complete each test was recorded. The difference in the time was analyzed with the use of analysis of variance. The agreement between the measured horizontal, vertical, and torsional deviations of the 3 methods was analyzed using mountain plot and Bland-Altman plot. The agreement of the measured deviations were calculated from the mean difference ($\bar{d}$) and standard deviation of the difference (s). The limits of agreement were calculated as $\bar{d} \pm 2s$. The mean difference ($\bar{d}$) was calculated as measurements obtained when the computerized test was used minus measurements obtained when the conventional test was used.

Thus, when one compares the results of the conventional and the computerized tests by Bland-Altman plot, a positive notation indicates a greater measurement with the computerized test, and a negative notation indicates a greater measurement with the conventional test. The differences in the limits of agreement between both computerized versions of the tests were analyzed with the paired *t* test. Systematic and proportionate deviations between different versions of the test were investigated with Deming regression models, which detect systematic and proportionate bias between 2 tests by trying to find the line of best fit for a two-dimensional dataset. The resulting regression equation is similar to that of linear regression, where

y represents the computerized version, *x* the conventional test, *a* the intercept, and *b* the slope coefficient, that is, $y = a + bx$. Deming regression analysis differs from the simple linear regression in that it accounts for errors in observations on both the x- and the y-axis with the intercept and the slope coefficient of the model used to test for the presence of systematic and proportionate bias respectively. Statistical analysis was performed using the statistical package for the social sciences version 15.0.1 (SPSS Inc, Chicago, IL) and MedCalc version 12.2.1 (MedCalc Software, Mariakerke, Belgium).

Results

A total of 82 patients (48 men) were included in the study. The mean age of the studied patients was 34.3 years with a standard deviation of 12.5 years (range, 22-56 years). In mountain plot analysis, measured horizontal deviation in the conventional test showed better agreement with those in the projector version than those in the monitor version. The agreement with the measured vertical and torsional deviation in the conventional test was quite similar for both the projector version and the monitor version. Results were similar for both right and left eyes (Figure 5).

Bland-Altman plots show the mean difference and the SD of the difference between the conventional test and each of the monitor version and the projector version. For both versions, the limits of agreement were within 5^{Δ} for the measured vertical deviation and within 3° for the measured torsional deviation, suggesting a good agreement between the measured vertical and torsional deviation in the conventional test and both computerized versions of the test. For vertical and torsional measurements, the difference in the agreement between both computerized versions of the tests was statistically insignificant for right and left eyes (Table 1). For the measured horizontal deviation, the SD of the difference was much lower in the projector version (limits of agreement, $<5^{\Delta}$), indicating better agreement with the conventional test than in the monitor version (limits of agreement, $>5^{\Delta}$). For horizontal measurements, the difference in the agreement between both computerized versions of the test was statistically significant ($P < 0.001$) for right and left eyes.

The relationship between the deviations measured by the conventional test and those measured by the computerized versions were analyzed by the use of Deming regression analysis (e-Supplements 1 and 2, available at jaapos.org). The intercepts in all scores—except the torsional scores in the projector version—were not close to zero, indicating a presence of systematic difference between the different methods for measurement, as the measured deviation tended to be smaller in both computerized versions of the test. The slopes of the scores were close to 1 in most cases, indicating little proportionate difference between the three methods for measurement and minimal change in the discrepancy between measurements with larger deviations.

The mean time taken to complete the conventional test was 461 ± 78 seconds; the monitor version, 466 ± 84 seconds; and the projector version, 470 ± 85 seconds. The difference in the
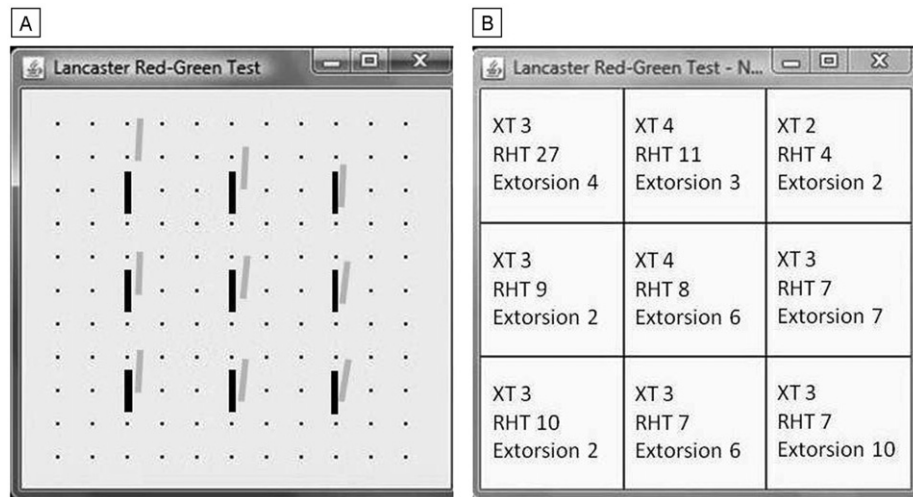
FIG 4. The display result of the computerized version of the Lancaster red-green test plotting the deviation of the right eye with the left eye fixing in a representative case with right superior oblique paresis and secondary right inferior oblique overaction. A, Chart plot displaying the patient's response in different gaze directions. B, Numerical plot displaying the calculated horizontal, vertical, and torsional deviations in different gaze directions.

time needed to complete the test was statistically not significant among the three groups ($P = 0.43$).

Discussion

Although the prism and alternate cover test in different positions of gaze is the standard for measurement of ocular misalignment, it provides no torsional information and may require considerable time and effort. In addition, repeatable gaze directions are difficult to ensure from one examiner to the other. The Lancaster red-green test, on the other hand, is a repeatable and a rapid method for assessing ocular misalignment.[6] The present study evaluates a simple model for computerizing the Lancaster red-green test and eliminates the need for a special screen or flashlight.

A number of computerized versions that allow subjective measurement of the ocular alignment in different gazes have been tested. Thompson and associates[7] were the first to describe an automated method for measurement of ocular motility in which a personal computer and a joystick were used. They, however, investigated it using a very short distance (25 cm) and a 20-inch display. They found that the shape of the oculomotor fields obtained using the computerized version was similar to that obtained from the conventional Hess screen. However, their computerized version tended to measure a slightly converged displacement of the plots relative to the conventional electric Hess chart and to record larger deviations, particularly in patients with incomitant fields. However, the test–retest reliability and the diagnostic value of the charts obtained were similar for both instruments. There was no significant difference between the durations of the examinations with the conventional test and the computerized version.

Watts and colleagues[8] compared the Assaf Ocular Motility Analyzer (OMA), to the conventional Lees screen and found that the deviations measured with OMA were larger in the horizontal direction and smaller in the vertical direction than those measured with the Lees screen. Although the OMA did not save time, patients found the test easier to perform than the Lees screen. Although both the Thompson model and the OMA have software programs to allow measurement of ocular torsion, their value in measuring subjective torsion was not reported.

Watts and colleagues[8] found significant difference between scores obtained with the conventional test and those obtained with the OMA for the right eye but not for the left eye. They suggested that discrepancy could be attributable to a systematic error within the OMA software package or to the difference in working distance used by the two methods. For the present study, the scores of the right eye were separated from the left eye to analyze each one separately, and no significant differences were noted between eyes.

In the present study, the measured vertical and torsional deviations by both computerized versions of the test were in good agreement with those measured by the conventional test. For measured horizontal deviations, the projector version, however, had a better agreement with the conventional test than the monitor version. Deming regression analysis showed systematic difference between the conventional Lancaster red-green test and the computerized version with a tendency to record smaller deviations in both computerized versions of the test. There was little proportionate difference indicating that level of agreement was constant irrespective of the magnitude of deviation.

The computerized version of the test was performed using red-blue targets and red-blue glasses instead of
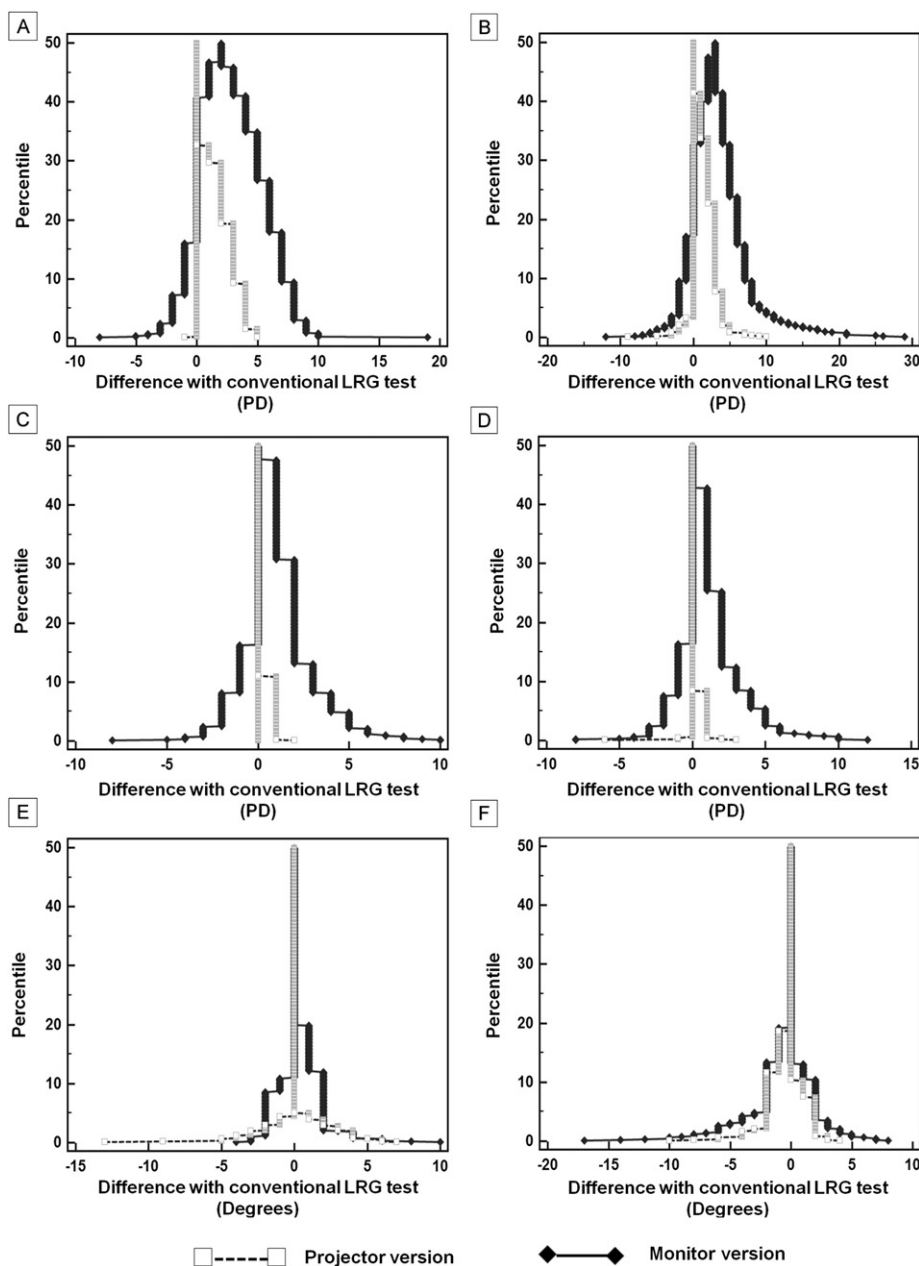
FIG 5. Mountain plots showing the folded cumulative distribution of the difference between the conventional Lancaster red-green test and both computerized versions of the test (difference = conventional test minus computerized version): measured horizontal deviation of the left eye (A) and right eye (B); measured vertical deviation of the left eye (C) and right eye (D); and measured torsional deviation of left eye (E) and the right eye (F). If the 2 tests are unbiased with respect to each other, the mountain will be centered over zero. For horizontal measurements, the mountains of both computerized versions were shifted to the right, indicating that the measurements obtained in the computerized tests tended to be lower, especially in the monitor version. For vertical and torsional measurements, the mountains of both computerized versions were centered close to zero.

the red-green ones used in conventional test because blue targets were more efficiently filtered on a computer monitor using a blue filter than green targets were by green filters. Nevertheless, it is worth noting that in the projector version, the conventional red-green targets and filters could have been used because green targets were efficiently filtered with green filter when using projector display.

The difference in time needed to complete the test between the conventional test and the computerized version was statistically insignificant. Most of the time in the conventional test was needed for copying the results on the screen to the paper plot by the operator, whereas in the computerized versions time was needed mainly for adjusting the target by the patient using the joystick. Nevertheless, patients who were more familiar with using

Table 1. Limits of agreement with conventional test for computerized versions of Lancaster red-green test

	Left eye			Right eye		
	Monitor	Projector	*P* value	Monitor	Projector	*P* value
Horizontal deviation, PD	−2.4 (−8.9 to 4.1)	−0.7 (−4.9 to 3.5)	<0.001	−2.9 (−10 to 4.9)	−0.6 (−4.6 to 3.4)	<0.001
Vertical deviation, PD	−0.8 (−4.7 to 3.1)	−0.6 (−4.2 to 3.0)	0.10	−0.8 (−4.4 to 3.0)	−0.6 (−4.3 to 3.1)	0.16
Torsional deviation, degrees	0.2 (−2.1 to 2.5)	0.2 (−2.2 to 2.5)	0.84	0.2 (−2.1 to 2.5)	0.2 (−2.2 to 2.6)	0.88

PD, prism diopters.
Values are mean difference (95% CI).

computers and joysticks seemed to require less time than those who were less familiar with computers. Finally, results of the computerized test have the advantage of being able to be immediately stored and transmitted electronically.

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