Applied Computer Systems for Strabismus Screening

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Objective: *To assess the accuracy of a computer system for strabismus screening.*

Material and Method: *A cross-sectional analytical study was conducted in four provinces representing four geographic regions of Thailand. Three hundred fifty four students who had visual acuity of less than 20/40, assessed by their school teachers and completed an eye examination with orthoptic measurement were included. Two digital images were taken, using a flash, with each student looking at a target at distances of 1 m and 6 m. The central corneal light reflex ratio (CCLRR) from the digital image was automatically calculated from an image analysis algorithm for strabismus screening. The study compared the computer results from the digital images with the results of the strabismus examinations.*

Results: *Pre-test probability for strabismus in preschool and school children post visual screening was about 15%. The likelihood ratio for high-risk, intermediate-risk, and low-risk from the photographs were 17.44, 1.51, and 0.76, respectively. Post-test probability for high-risk, intermediate-risk, and low-risk from the photographs were 75%, 21%, and 12%, respectively.*

Conclusion: *It is possible to develop a computer system for strabismus screening. The likelihood ratio for high-risk from the photographs was 17.44.*

Keywords: *Strabismus, Screening, Computer, Probability, Likelihood ratio*

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Strabismus is a condition in which the eyes are not properly aligned with each other. It typically involves lack of coordination, either esotropia or exotropia. Without correction, this can result in secondary clear vision in the one straight eye, and decreased vision in the deviated eye.

Strabismus may induce amblyopia, commonly known as lazy eye, while chronic blurred vision may induce strabismus. Early treatment of strabismus and amblyopia in infancy can reduce the chances of developing blindness and poor depth perception. Late treatment will result in difficulty for reversing these conditions.

In Thailand, the timing and frequency of screening examinations for strabismus are not well established. Some ophthalmologist or specially trained personnel is recommended, using visual inspection along with assessment of ocular alignment. Eye screening tests in the general population can detect severe amblyopia, obvious strabismus, and high refractive errors(1). In developing countries, the human resources for eye screening, especially ophthalmologists are usually scarce. Therefore, screening of strabismus using digital photos as well as a computer program is appropriate in areas that have limited health personnel.

Despite suboptimal performance of the screening tests, early detection along with the management of strabismus is essential. The detection may be done using imaging technology (photo screening) and visual processing programs(2-4). The Medical Technology Incorporated (MTI) photo-screener shows high sensitivity and specificity for refractive errors, but low sensitivity in detecting strabismus, especially at angles of less than 10 prism diopters(1). Furthermore, the results depend on the experience of the investigator(3,4).

The present study examined the feasibility of detecting strabismus from digital images, using specifically designed computer software. This study is part of the development of a computer system for strabismus screening and management project. Our

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aim was to set up an appropriate system to detect strabismus nationwide.

Material and Method

The proposal was approved by the Ethics Committee of the Faculty of Medicine, Prince of Songkla University. This diagnostic study was a retrospective, masked study. Photographs were taken from schoolchildren who enrolled in a study "assessing the accuracy and feasibility of a refractive error screening program conducted by school teachers in pre-primary and primary schools in Thailand"[5]. The study was conducted between October 2011 and January 2012. A two-stage cluster sampling was used to select four representative provinces from each of the four regions. The schools selected were based on school size and the willingness of teachers to participate in the study. Five thousand eight hundred eighty five children from pre-primary (4 to 6 years), and primary school grades (7 to 12 years) participated in the study. Participating teachers were trained in performing visual acuity (VA) test, and children who had VA of less than 20/40 were referred to the research team (ophthalmologists and ophthalmic nurses) for further examination at the local provincial hospital.

Three hundred fifty four students completed the eye examination with the research team including VA measurement, an external examination, and refraction and orthoptic measurement. The alternate prism cover test was used to detect ocular alignment as the gold standard. The test was performed by one of the three ophthalmologists (Tengtrisorn S, Teerawattananon K, and Wongkittirux K) who had more than 10 years experience in clinical practice. For clinical analysis, cases of phoria who had normal visual development were defined as having normal eye. Cases showing some strabismus, but in some positions having straight eye, or intermittent strabismus, were classified as strabismus (Table 1). The subjects classified as strabismus at 1 m or 6 m were considered as having strabismus.

A compact, Fuji camera model FinePix S602 Zoom 6X optical zoom lens was used to take the digital images. Two digital images using a flash were taken by an assistant researcher of each student, who was positioned 1m from the camera, and looking at targets 1 m and 6 m away. All digital images were 2,048x1,536 pixels. The digital images were then transferred to a computer in which the images were analyzed by specifically designed software consisting of four steps, face detection, eye detection, limbal and corneal reflex detection, and central corneal light reflex ratio (CCLRR) calculation (Fig 1). Finally, the CCLRR was compared with normal reference values, as described previously[6]. CCLRR was the ratio of the summated bilateral distance between position of central corneal light reflex (CCLR) and nasal limbus to the summated bilateral horizontal corneal diameters (Fig. 1). The normal range at near/at distance were 0.4460 to 0.484/0.421 to 0.482. The indeterminate ranges at near were 0.435 to 0.445 and 0.485 to 0.495, and indeterminate ranges at distance were 0.403 to 0.420 and 0.483 to 0.500. "Out-of- range" was defined as a CCLRR beyond these outer limits (Table 2).

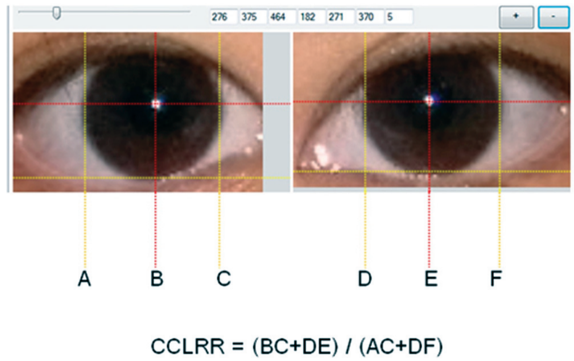

Fig. 1 Central corneal light reflex measurement.

Statistical analysis

The distribution of values of CCLRR measured from the 1 m and 6 m images were examined and compared between subjects classified clinically

Table 1. Strabismus examination results

Strabismus examination results	Number (%) at distance (6 m) n = 340	Number (%) at near (1 m) n = 340
Ortho	261 (75.8)	159 (46.8)
Phoria*	37 (10.8)	133 (39.1)
Tropia**	42 (12.4)	48 (14.1)

* Included esophoria and exophoria
** Included esotropia, exotropia, and intermittent strabismus

Table 2. Central corneal light reflex ratio for normal, indeterminate and abnormal ranges

Result	Near (n = 63)	Distance (n = 63)
Normal	0.446 to 0.484	0.421 to 0.482
Indeterminate	0.435 to 0.445, 0.485 to 0.495	0.403 to 0.420, 0.483 to 0.500
Out-of- range	<0.435, >0.495	<0.403, >0.500

Near = looking at target 1m, Distance = look at target 6 m

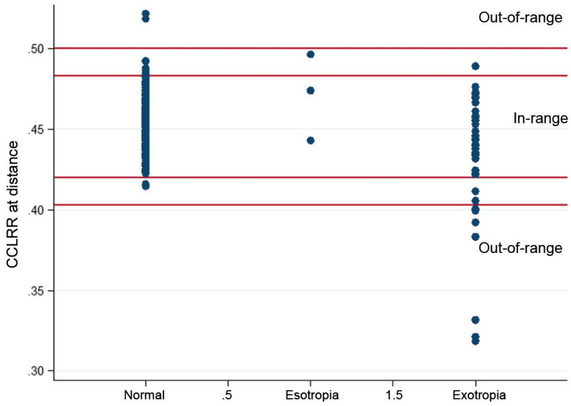

Fig. 2 Distribution of central corneal light reflex ratio determined from photographic images at 6 m according to clinical classification of normal, esotropia, or exotropia at 6 m. The in-range, indeterminate, and "out-of-range" values[5] are indicated by the horizontal lines.

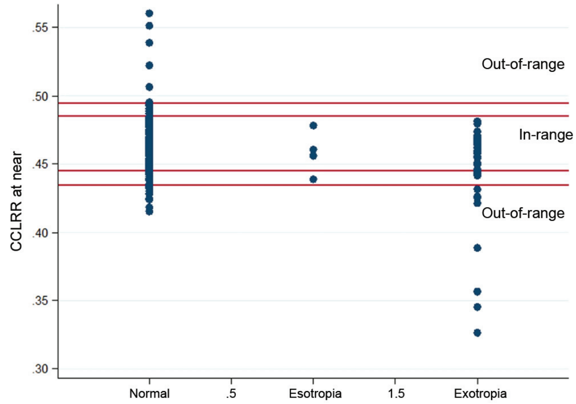

Fig. 3 Distribution of central corneal light reflex ratio determined from photographic images at 1m according to clinical classification of normal, esotropia, or exotropia at 1 m. The in-range, indeterminate, and "out-of-range" values[5] are indicated by the horizontal lines.

as normal, strabismus, exotropia or strabismus, or esotropia (Fig. 2, 3). Subjects were classified as being in-range, indeterminate, or "out-of-range" according to the normal ranges for images taken at 1 m and 6 m as determined in the earlier study[6].

Subjects were then re-classified into three levels of risk, high, if both near and distance CCLRR values were "out-of-range", intermediate, if only one image was "out-of-range" or neither was "out of range" and one or both were in the indeterminate range, or low, if both images were in-range.

From the present data, likelihood ratio along with 95% confidence intervals were determined for each risk group, and the likelihood ratio and post-test probabilities of being strabismus calculated for the subject population (in which prevalence of strabismus was about 15%). All analyses were performed using the Stata statistical software (STATA MP 14.1 Copyright 1985-2015 StataCorp LP).

Results

Of the 708 photographs taken from the 354 children, which yielded 708 images, 340 were enrolled into the study. Fourteen children were excluded, because of the poor quality of the images. Subjects comprised of 163 (47.9%) females and 177 (52.1%) male. Clinical examination revealed percentages of ortho, phoria, and tropia of 75.8%, 10.8%, and 12.4%, respectively at 6 m, and 46.8%, 39.1%, and 14.1%, respectively at 1 m (Table 1). Analysis of distance images indicated that in-range, indeterminate, and "out-of-range" subjects accounted for 93.5%, 3.8%, and 2.6%, respectively, and that of near images 80.6%, 9.4%, and 10.0%, respectively (Table 3).

On regrouping, combining distance and near image analysis, 79.1%, 18.5% and 2.4% were in the low, intermediate, and high-risk groups, respectively (Table 4). Likelihood ratios (95% CI) for low, intermediate, and high-risk groups were 0.75 (0.50, 1.10), 1.51 (0.75, 2.82), and 17.44 (3.11, 176.28), respectively. Thus, the chance of having strabismus in children categorized as low-risk was less than those in the normal population, while the odds of having strabismus in children categorized as intermediate-risk and high-risk increased by about 0.5, 17 times respectively. Combining high- and intermediate-risk groups, the sensitivity and specificity (95% CI) of the test were 38% (25%, 53%) and 82% (77%, 86%), respectively.

Discussion

Strabismus is a presenting sign of blurred vision, or the cause of amblyopia. Whenever strabismus is detected, the patient should undergo an investigation for other abnormalities such as cataract, retinoblastoma, or retinal disease, along with the possible management,

Table 3. Photograph results

Photograph results	Number (%) at distance (6 m) n = 340	Number (%) at near (1 m) n = 340
In-range	318 (93.5)	274 (80.6)
Indeterminate	13 (3.8)	32 (9.4)
Out-of- range	9 (2.6)	34 (10.0)

Table 4. Statistical analysis of central corneal light reflex ratio (CCLRR) from photograph

Photograph result	Strabismus	Normal	Total	Odds	Likelihood ratio (95% CI)	Post-test probability
Low-risk	31	238	269	0.130	0.75 (0.50,1.10)	0.12
Intermediate-risk	13	50	63	0.26	1.51 (0.75,2.82)	0.21
High-risk	6	2	8	3	17.44 (3.11,176.28)	0.75
Total	50	290	340	0.172	1	0.15

Point estimates (95% confidence interval):
Combining high- and intermediate-risk groups, sensitivity = 38% (95% CI 25%, 53%), specificity = 82% (95% CI 77%, 86%)
In this subject population, positive predictive value for high-risk group = 75% (95% CI, 35%, 97%), negative predictive value = 88% (95% CI, 84%, 92%)

or some form of treatment, to improve visual development, especially in children. There are many methods or instruments for amblyopia screening including refractive error and strabismus, such as MTI photo-screener[2,3,7,8], plusoptiX S04 photo-screener[9], Otago screener[10], and photo-screening camera[11]. The sensitivity and specificity of these methods are 65 to 83% and 79 to 98%, respectively. However, the sensitivity and specificity for strabismus screening from MTI photo-screener[3] were reported to be 23 to 50%, 76 to 96%, respectively. In the present study, the sensitivity is quite low, but the specificity is quite high. This may be because of the Kappa angle, the low severity of strabismus, or the accuracy of the cutoff point. Pre-test probability in preschool and school children post visual screening was about 15%. Likelihood ratio for high-risk from image analysis and categorizing was about 17. Thus, the odds of having strabismus in children categorized as high-risk increased about 17 times, compared with pre-test values. Thus, the chance of having strabismus in children categorized as low-risk was less than that in the normal population while the odds of having strabismus in children categorized as intermediate-risk increased about 0.5 times. Post-test probability of strabismus, based on our samples with 15% prevalence of strabismus for high-risk was 75%. It means that the children in high-risk group had a probability of having strabismus of 75%.

In Thailand, visual screening programs are provided for schoolchildren depending on completeness of the school or their community. The frequent problem for running programs is the lack of medical personnel. For visual screening, teachers can measure VA in their school, but strabismus screening needs to be conducted by an experienced person.

Our suggestion for global eye screening is that all children should have visual screening, and those with a VA of less than 20/40 should have digital image screening for strabismus detection. The children

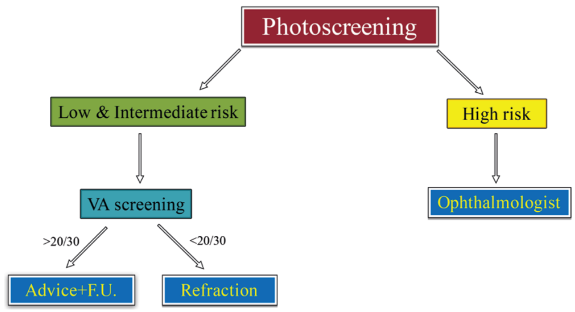

Fig. 4 Global eye screening management.

who fail both visual screening as well as the digital image screening should be sent to an ophthalmologist for proper management, while children who fail only visual screening should be sent to acquire glasses, as the major cause of VA screening positive is refractive error. This can be corrected by glasses[5]. With this program, we can reduce the burden of medical personnel, and provide effective management. Children in the intermediate-risk and low-risk groups still have a chance of contracting strabismus such as intermittent strabismus or small angle strabismus. For this reason, the screening should be repeated in subsequent years (Fig. 4).

Eye screening should be provided worldwide, especially for children. To perform mass population eye screening, the instruments used should be easily usable by trained lay-persons who should be able to detect the major conditions associated with amblyopia such as strabismus and high refractive error, especially in young children. The computer program should have an automatic mode and a manual mode for making a correct point in case of unclear corneal reflex. For various economic and logistical reasons, the cost effectiveness for eye screening from photographs should be evaluated.

A limitation of the present study is that some photography showed poor visualization of limbus or corneal reflex, so the computer marked an incorrect point. The sample size was quite small and the prevalence of strabismus was low. The prism cover test was performed by only one ophthalmologist without confirmation from others, though the three ophthalmologists performing the test had long-term experience in clinical practice. The present study showed low sensitivity but high specificity, so it may be necessary to adjust the cutoff-points in the future. Subjects classified as intermediate- or low-risk should be advised to be observed and undergo repeat screening.

Conclusion

It is possible to develop a computer system for strabismus screening. The likelihood ratio for the high-risk category was about 17. In our VA-screened children, the prevalence of strabismus was 15%, the post-test probability of having strabismus in the high-risk category using this computer system was 75%.

What is already known on this topic?

Strabismus may induce amblyopia while chronic, blurred vision may induce strabismus. Early treatment of strabismus and/or amblyopia in infancy can reduce the chances of developing blindness and depth perception problems. Eye screening tests, in the general population, can detect eye diseases. In developing countries, the human resources for eye screening, especially by ophthalmologists, are usually scarce.

What this study adds?

It is possible to develop a computer system for strabismus screening. Screening of strabismus using digital photos is appropriate in areas that have limited health personnel.

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Potential conflicts of interest

None.

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ระบบคอมพิวเตอร์ประยุกต์เพื่อคัดกรองตาเข

สุภาภรณ์ เต็งไตรสรณ์, กัลยา ตีระวัฒนานนท์, ขวัญใจ วงศ์กิตติรักษ์, พรชัย พฤกษ์ภัทรานนท์, นิมมิตา คุ้มเดช

วัตถุประสงค์: *เพื่อประเมินความแม่นยำของระบบคอมพิวเตอร์เพื่อคัดกรองตาเข*

วัสดุและวิธีการ: *การศึกษาภาคตัดขวาง ทำใน 4 จังหวัด ซึ่งเป็นตัวแทนของภาคในประเทศไทย นักเรียน 354 คน ได้รับการตรวจโดยสายตาน้อยกว่า 20/40 ตรวจโดยครู ได้รับการตรวจอย่างสมบูรณ์รวมถึงการวัดตาเข ภาพถ่าย 2 ภาพ ได้รับการถ่ายโดยใช้แฟลช นักเรียนจะมองเป้าหมายที่อยู่ระยะ 1 เมตร และ 6 เมตร อัตราส่วนของจุดแสงตกกลางตาดำ (CCLRR) จากภาพถ่ายคำนวณอัตโนมัติจากการคำนวณวิเคราะห์ภาพถ่ายเพื่อคัดกรองตาเข การศึกษาเปรียบเทียบผลคอมพิวเตอร์จากภาพถ่ายและผลการตรวจตาเข*

ผลการศึกษา: *ความน่าจะเป็นก่อนการทดสอบตาเขในเด็กก่อนวัยเรียนและวัยเรียนหลังจากการคัดกรองสายตา เป็นร้อยละ 15 อัตราส่วนความเป็นไปได้สำหรับกลุ่มความเสี่ยงสูง ความเสี่ยงปานกลาง และความเสี่ยงต่ำ จากภาพถ่าย เป็น 17.44, 1.51 และ 0.76 ตามลำดับ ความน่าจะเป็นหลังการทดสอบสำหรับกลุ่มความเสี่ยงสูง ความเสี่ยงปานกลาง และความเสี่ยงต่ำจากภาพถ่ายเป็นร้อยละ 75, 21 และ 12 ตามลำดับ*

สรุป: *มีความเป็นไปได้ที่จะพัฒนาระบบคอมพิวเตอร์เพื่อคัดกรองตาเข อัตราส่วนความเป็นไปได้สำหรับกลุ่มความเสี่ยงสูงจากภาพถ่ายเป็น 17.44*