ORIGINAL RESEARCH

Vision screening of preschool children by eccentric photorefraction using a digital camera

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Abstract

Aims: To determine the validity of a photorefraction screening protocol using computer-aided techniques; to make recommendations regarding the cost and practicability of establishing a photorefraction screening service for Hong Kong preschool children; and to determine the prevalence of visual problems in Hong Kong kindergarten children.

Materials and methods: We calibrated a digital photorefractor, and a semiautomatic computer program was designed to determine the refractive error based on the image captured. An eye examination was carried out, followed by photorefraction screening, in 854 kindergarten children. We compared the cost of photorefraction with the digital photorefractor with photorefraction with a commercially available photorefractor, the MTI.

Results: Clinical examination showed that 16.9% of children had a visual problem. Myopia was not yet prevalent (only 1.1% of the children had myopia of 1 D or more), and the most common refractive error was astigmatism (10.7%). Strabismus was found in 2.3% and anisometropia in 1.6% of the children, so that about 4% of the children were at risk for amblyopia. The photorefractor had a sensitivity of 71.0% and a specificity of 97.2%. The main cause of false-negative screening results was low astigmatism falling into the null zone of the photorefractor.

Conclusions: A kindergarten-based vision screening scheme for three-year old children is viable, and the calculated cost per child is HK$23.90. The method is much more sensitive than vision measurement. Astigmatism was the most prevalent refractive error in preschool children.

Key words: Digital photorefraction, Eye problems, Preschool children, Hong Kong

Introduction

Eye-care practitioners and researchers recommend that children's vision should be screened at as early an age as possible.[1-4] In Hong Kong, screening takes place in primary school, later than is ideal for effective treatment of amblyopia and strabismus. Edwards and Yap recommended that screening should be included as part of the health care provision to preschool children.[5] Referral criteria appropriate for Hong Kong Chinese preschool children have recently been established;[6] however, the vision screening techniques used for primary school children are not suitable for preschool children. Chan and co-workers have examined the validity of a photorefractive technique for the vision screening of preschool children.[7]

The main drawback to a conventional photographic technique, however good, is that it produces photographs. Photographs must be developed, viewed, analysed and catalogued. Children who are identified as having problems need to be contacted and appointments made for full examination, and in the meantime the photographs must be stored and then retrieved. These are all labor-intensive activities.

The same technique, using a digital camera interfaced with a computer, allows instant viewing of photographs, computer analysis of the images, computer cataloging and storage of data on disk. While the set-up costs are higher than for conventional camera systems (although digital cameras are rapidly decreasing in price), the recurrent costs associated with a computerized photorefractor are very much less than for a film-based photorefractor.

The aims of this study were:

1. To determine the validity of a photorefraction screening protocol using modern computer-aided techniques to obtain, analyze and store the photorefraction images.
2. To make recommendations regarding the cost and practicability of establishing a photorefraction screening service for Hong Kong preschool children.
3. To determine the prevalence of visual problems in Hong Kong children between the age of three and six years.

Materials and methods

Subjects

Thirty kindergartens in different districts of Hong Kong were invited to participate. Seven kindergartens accepted the invitation, and five kindergartens finally participated. Letters were sent to parents of all the children to explain the project and to invite participation. In order to encourage a high participation rate, the examinations were arranged for evenings, Saturdays or Sundays if required. Sixteen hundred and five invitation letters were sent; the parents of 963 children signed informed consent forms and 854 children were eventually examined. The participation rate was therefore 53%. Three children refused to co-operate for either clinical examination or photorefraction.

Clinical assessment of visual problems

Clinical assessment was carried out either at the Optometry Clinic in the Hong Kong Polytechnic University or in the kindergarten. The examination comprised an assessment of habitual vision (that is, unaided vision or vision with spectacles if worn) at 4 m using a letter-matching chart (Sheridan-Gardiner with confusion bars) static retinoscopy without cycloplegia, strabismus assessment using the Hirschberg test, and cover tests. External ocular health and internal eye examinations were carried out as indicated.

1. Habitual vision assessment

Habitual vision assessment was the first procedure undertaken and was done with the room light fully turned on. Monocular vision was measured for each eye using a Sheridan-Gardiner letter-matching chart with confusion bars. This consists of a flip chart and a key card. The flip chart has 15 pages with a single letter on each page. There are five Snellen acuity levels (4/20, 4/12, 4/8, 4/6 and 4/4) and three letters for each level. Each letter is surrounded by four interaction bars; seven letters (A, O, U, T, H, X, V) are used in the chart and these seven letters are also printed on the key card. The illumination level for the five kindergartens ranged from 230 lux to 310 lux.

During the test, the examiner held the flip chart at a distance of 4 m from the child. The child held the key card and matched the letter on the key card with the one shown on the flip chart. When a letter was shown, the child was encouraged to give a response.

The recorded vision was the best acuity for which two out of the three letters had been correctly matched. Young children were taught to match the largest letter first at a very close distance. As they became familiar with the test, the examiner moved further and further away until he was 4 m from the child.

2. Static retinoscopy

With the room light switched off, refractive error was measured by noncycloplegic static retinoscopy at a working distance of 67 cm. The child under test was directed to look at a flashing yellow LED light attached at the edge of the lens of the photorefractor, which was positioned 4 m away. Three pairs of children's spectacles of different sizes edged with multicoated plastic lenses of power +1.50 D were used as working-distance and fogging lenses to discourage accommodation during retinoscopy. The pair which best fitted the child was used. Loose trial lenses were used for neutralizing the retinal reflexes.

The teacher of the class involved sent a group of four or five pupils for screening at one time. The waiting children were able to see the examinations being carried out, and this helped familiarize the children with the environment and the testing procedures.

3. Strabismus assessment

With the room light switched on, the alignment of the eyes was assessed using the unilateral and alternating cover test. The child was asked to look at the flashing LED, and the unilateral cover test was used to determine whether or not the child was strabismic. A prism bar was used to measure the angle of deviation of the eye in cases of heterotropia.

Colour vision was not a criterion in this study. A child meeting any of the following criteria was considered to have a visual problem.[6]

- strabismus
- habitual vision with acuity less than 6/12 in either eye
- more than one Snellen line of difference in habitual vision between the two eyes
- hyperopia $\geq$2.00 D (noncycloplegic, negative cylinder format) in either eye
- Astigmatism $\geq$1.00 D (noncycloplegic, negative cylinder

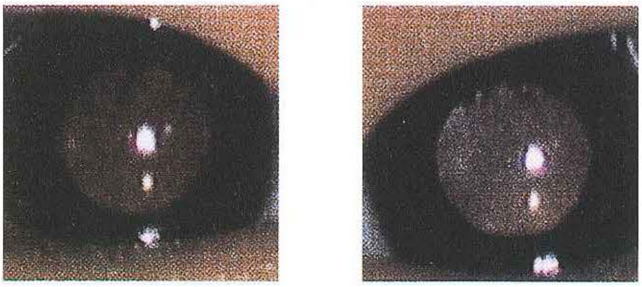
format) in either eye

- Anisometropia $\geq$1.25 D (noncycloplegic, negative cylinder format) between the two eyes
- Myopia $\geq$1.00 D (noncycloplegic, negative cylinder format) in either eye

The photorefractor

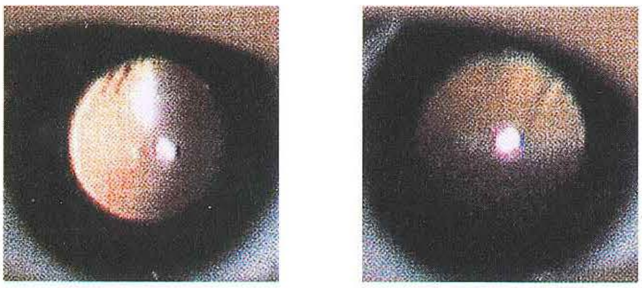
The photorefractor consisted of a Minolta RD-175 digital camera fitted with a Minolta AF Reflex 500/8 catadioptric lens. A twin flash tube unit (Olympus T28) was fixed to the catadioptric lens, and the distance from the flash to the edge of the effective camera lens aperture (the eccentricity, *e*, of the photorefraction system) was 19.25 mm. One flash was orientated vertically and the other horizontally, in view that oblique astigmatism being rare in preschool children in Hong Kong.[8] The camera system was connected to a Macintosh 5300CS notebook computer, and an image manipulation program (Adobe Photoshop 4.0) was used to display and handle the images and to reduce the size of the photographs for refractive error analysis.

We calibrated the photorefractor using data from artificial eyes set at +6.00 D to -6.00 D in 0.50 D steps. Three pupil sizes were used: 5 mm, 7 mm, and 9 mm. The reflex size used for calibration was the average of measurements obtained on three different occasions. For a given photorefractor used at a set distance, the size of the photorefraction reflex depends on the refractive error and the pupil size: the smaller the pupil size, the smaller the reflex. For a given pupil size there is a range of low refractive errors, the photorefractor null zone, for which no reflex is seen. For the digital photorefractor used, reflexes were obtained for refractive errors $\geq$+1.00 D and $\leq$-1.50 D with a 5 mm pupil and for $\geq$+1.00 D and $\leq$-1.00 D with both 7 mm and 9 mm pupils. The photorefractor cannot identify myopes of less than -1.50 D if the pupil size is 5 mm or less and the null zone (for which refractive errors are not identified) is -0.75 to +0.75 D. Examples of the photorefraction reflex obtained are given in **Figure 1**.



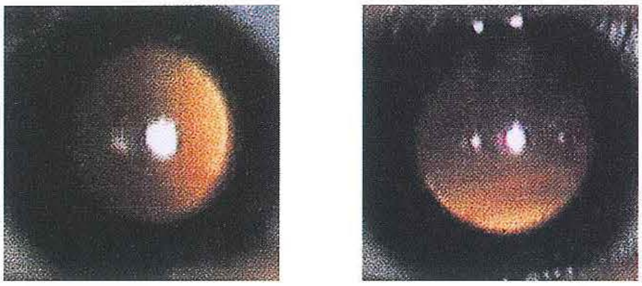
RE LE

Strabismus - LE Esotropia



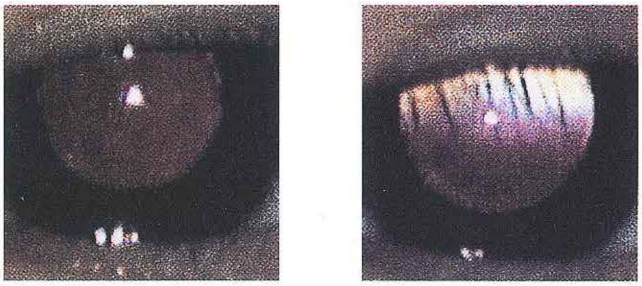
RE LE

Myopia - RE - 3.25 -0.50 x 180



RE LE

Hyperopia - RE +3.25 -0.50 x 90



RE LE

Astigmatism - LE +0.75 -2.00 x 170

Figure 1. Example of photorefraction reflexes.

Photorefractive assessment of visual problems

During photorefraction, the room light was switched off and the child was asked to look at the flashing LED lights. We allowed 10 to 15 seconds between the room being darkened and taking the photographs to allow the pupils to dilate. Two pictures were taken of each child, one with the flash set to refract the horizontal meridian of the eyes and the other with the flash set to refract the vertical meridian of the eyes. Additional photographs were taken if the photorefraction image shown on the monitor was not good enough for image evaluation or measurement or if the pupil diameter was less than 5 mm.

The monitor images were measured, as described above, to determine the refractive error, and the following criteria were used to determine whether the child would have "passed" or "failed" the screening.

- strabismus
- hyperopia $\geq$2.00 D (noncycloplegic, negative cylinder format) in either eye
- astigmatism $\geq$1.00 D (noncycloplegic, negative cylinder format) in either eye
- anisometropia $\geq$1.25 D (noncycloplegic, negative cylinder format) between the two eyes
- myopia $\geq$1.00 D (noncycloplegic, negative cylinder format) in either eye

Results

Sample

The 854 kindergarten children recruited were divided by age into eight groups as shown in **Table 1**. The mean age was

Table 1. Distribution of subjects by age and sex.								
	Age (months)							
	<36	36-41	42-47	48-53	54-59	60-65	66-71	72-76
Boys	12	21	55	96	86	86	99	38
Girls	7	21	49	68	56	51	75	34
Total	**19**	**42**	**104**	**164**	**142**	**137**	**174**	**72**

was 56.88 (SD 11.03) months.

Subjects failing the habitual vision criteria

Only four children were wearing spectacles when they attended for examination. Habitual vision may therefore be considered equivalent to unaided vision in determining the prevalence of various standards of unaided vision. The children wearing spectacles were either high myopes or high astigmats, and three failed the habitual vision criteria despite wearing spectacles. Two of the four had strabismus.

Figure 2 shows the percentage of subjects meeting specific habitual vision criteria in the better eye and in the worse eye. Seventy-six children (8.9%) had habitual vision worse than 4/8 (6/12) in the worse eye and therefore failed the clinical criterion for habitual vision. Forty-five children (5.3%) had habitual vision worse than 4/8 (6/12) in the better eye. Habitual vision in the better eye is a measure of the vision available for daily living and educational tasks.

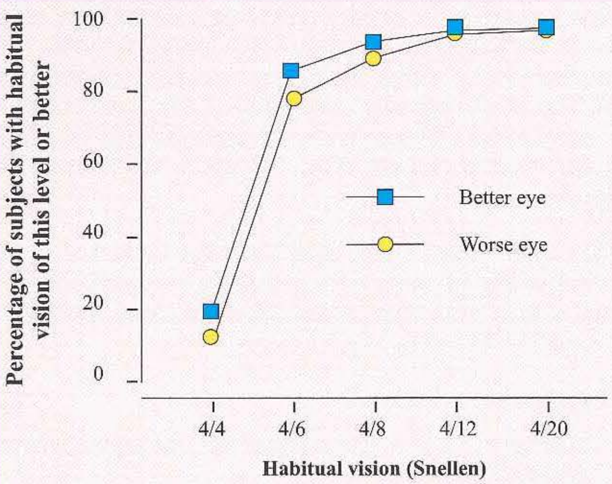


Figure 2. The percentage of subjects attaining each of five habitual vision levels.

Seventeen of the 76 subjects who failed the habitual vision criterion also had more than one line of difference in visual acuity between the two eyes. In addition, two subjects had more than one line of difference in visual acuity between the two eyes, although they had habitual vision in each eye of better than 4/8. Thus, a total of 78 children (9.1%) failed in the vision category of the clinical referral criteria.

Subjects failing the refractive error criteria

Nine subjects had myopia in at least one eye, ranging from -1.00 to -6.50 D. Thirty-five subjects had hyperopia, ranging from +2.00 to +5.75 D. Ninety-one subjects had astigmatism, ranging from 1.25 to 4.75 D, and fourteen subjects had anisometropia greater than 1.25 D, the largest refractive error difference being 8.00 D. This subject had refractive errors of RE +1.00 D and LE -7.00 D.

Subjects failing because they had strabismus

Twenty subjects (2.3%) were found to have strabismus. Ten were constant exotropes and five were constant esotropes. The remaining five were alternating exotropes. The relative ratio of exotropia to esotropia was therefore 3:1.

Others (ptosis)

Two subjects had unilateral ptosis and were regarded as having failed the examination. Their refractive errors were as follows:

Subject 1 (RE ptosis)	RE	+1.00 -1.75 x 165, VA 4/6
	LE	+0.25, VA 4/6
Subject 2 (LE ptosis)	RE	-0.25 -1.50 x 10, VA 4/12
	LE	-2.50 -0.50 x 180, VA 4/12

Prevalence of visual problems

Table 2 summarizes the number of subjects failing in each category and is therefore an estimate of the prevalence of the associated visual problems. Myopia was just beginning to develop in this group of children. The most prevalent refractive error was astigmatism of 1 D or more (10.7%), followed by hyperopia of 2 D or more (4.1%). Many subjects failed in more than one category.

Table 2. Number and percentage of subjects failing in each referral criterion in the clinical examination.

Visual problem	No. of subjects (%)
Habitual vision	78 (9.1)
Hyperopia	35 (4.1)
Myopia	9 (1.1)
Astigmatism	91 (10.7)
Anisometropia	14 (1.6)
Strabismus	20 (2.3)
Others (ptosis)	2 (0.2)

Applying the referral criteria listed above, 17% (SE 2.53) of the 854 subjects failed at least one of the clinical referral criteria. **Table 3** shows how they failed.

Table 3. The visual problems found in the 145 subjects who failed the clinical examination criteria. If vision of less than 6/12 had been the only criterion, then 77 problem cases would have been identified.

Clinical examination criteria failed	No. of subjects
Visual acuity only	13
Refractive error only	53
Strabismus	10
Vision and refractive error	57
Vision and strabismus	1
Refractive error and strabismus	4
Vision, refractive error and	5
Refractive error and ptosis	1
Vision, refractive error and ptosis	1
Total	**145**

Validity of photorefraction

Photorefraction correctly identified 103 out of 144 failed subjects; however, it also falsely identified 20 cases. The results are summarized in **Table 4**.

Table 4. A breakdown of photorefractive and clinical referrals and nonreferrals.

	Clinical examination result		
Photorefraction result	**Failed**	**Passed**	**Total**
Failed	103 (TP)	20 (FP)	123
Passed	42 (FN)	689 (TN)	731
Total	**145**	**709**	**854**

TP = true positive FP = false positive
FN = false negative TN = true negative

The sensitivity of photorefraction was 71.0%; that is, 71.0% of children who failed the clinical examination were identified by photorefraction. The predictive value of a positive test was 83.7%; that is, 83.7% of children identified by photorefraction as having a visual problem did actually have a problem.

The specificity of photorefraction was 97.2%; that is, 97.2% of the children found to have no visual problems in the clinical examination "passed" the criteria used for photorefraction. The predictive value of a negative test was 94.2%.

The false-positive and false-negative rates for photorefraction were respectively 2.8% and 28.9%. The false-positive rate may be considered satisfactory; however, the false-negative rate was not and will be discussed further.

A further method of describing the validity of a screening test is the use of the phi-coefficient. The following formula was used to calculate the phi-coefficient:

$$\text{phi-coefficient} = \frac{[(TP)(TN)-(FP)(FN)]}{\sqrt{(TP+FP)(FN+TN)(TP+FN)(FP+TN)}}$$

This measure has a range of values from -1.0 to +1.0. The closer the value to +1.0, the greater is the predictive validity of the screening test.[9] The phi-coefficient found was +0.73.

Characteristics of subjects with false-negative results

Forty-two subjects failed in the clinical examination but passed the photorefraction screening. Habitual vision was a criterion only in the clinical screening, and nine subjects failed the unaided vision criterion in the clinical examination but passed the photorefraction screening. The other 33 subjects either failed the refractive error or the strabismus criteria, or both. The characteristics of these 42 subjects who passed the photorefraction screening but failed in the clinical examination are summarized in **Table 5**.

Table 5. The visual problems found in 42 subjects who failed the clinical examination but passed the photorefraction screening.

Visual problems found in clinical examination of false-negative cases	No. of subjects (%)
Habitual vision only failed	9 (21.4)
Hyperopia	6 (14.3)
Myopia	0 (0.0)
Astigmatism	21 (50.0)
Anisometropia	1 (2.4)
Strabismus	3 (7.1)
Hyperopia + astigmatism	2 (4.8)
Total	**42 (100)**

Fifty percent of the subjects who failed the clinical examination but passed the screening had astigmatism associated with low degrees of spherical refractive error. All but one of these astigmats had with-the-rule astigmatism. There were no cases of oblique astigmatism among the false-negative results. All six hyperopic subjects missed by the photorefraction screening had been found to have hyperopia of either +2.00 D or +2.25 D in the clinical examination. No myope was missed. The degree of astigmatism missed by the photorefraction screening ranged from 1.25 D to 2.00 D. The refractive error of the misclassified anisometropia subject was as follows:

RE -0.25

LE +1.00 -0.50 x 180

Two of the three misclassified strabismic subjects had exotropia, while the other had esotropia. The angle of strabismus in the esotropic subject was 10 to 15 prism D, which may not be large enough to produce a detectable asymmetric corneal reflex. One of the exotropic subjects had intermittent exotropia, and it is possible that the eyes were straight when the photograph was taken.

Characteristics of subjects with false-positive results

Twenty subjects passed the clinical examination but failed in the photorefraction screening. Nineteen had astigmatism of 1 D or more on photorefraction, but had astigmatism of less than 1 D on clinical examination.

Discussion

Representativeness of the sample

One of the objectives of this work was to determine the prevalence of visual problems in Hong Kong children between the age of three and six years. Only 53% of the children in the participating kindergartens joined the study, and so it is necessary to consider whether this is likely to have introduced bias into the sample.

In order to explore the extent to which self-selection occurred, participating families were asked to complete a questionnaire in which they were asked to indicate the most important reason for joining the study. Five hundred and fifty-one families completed the questionnaires (a 64.5% response rate). Four hundred and fifty-one families (81.9%) indicated that they had wanted to know whether the vision of their children was good or not. Thirty-six families (6.5%) suspected their children had a vision problem. Thirty-two families (5.8%) hoped that their participation would help to develop a new vision screening technique. Other reasons for participation included a free eye examination, not knowing where to go for professional eye care and because the eye examination was provided by the university.

Assuming that 6.5% of all the participating families thought their children might have a visual problem, there were 55 such families (6.5% of 854). The overall participation rate in the five kindergartens was 53%. Assuming the most extreme case, that all the kindergarten families who thought their children might have a visual problem (55 families) participated, rather than just 53% of these families (29 families), then the frequency of visual problems would have been overestimated by 26. One hundred and forty-five out of 854 children had visual problems, giving a prevalence of visual problems of 17% (SE 1.29%). Subtracting 26 from this number gives a "corrected" prevalence of visual problems of 13.9% (SE 1.18%).

False-negative and false-positive screening results

In all cases of astigmatism misclassified as false-positive results, both the principal meridians of the affected eyes fell into the null zone of the photorefractor. Similarly, in the case of anisometropia which was misclassified, all four meridians (that is, of the two eyes) were in the null zone. The null zone means that astigmatism or anisometropia of up to 1.50 D could be missed by screening, and this is clearly a problem which should be addressed in order to improve the sensitivity of the screening method. To minimize the size of the null zone, a pupil size of 7 mm should be regarded as the minimum for an acceptable photorefraction result.

Ninety-five percent of the 20 false positive results were cases identified by screening as having astigmatism of 1 D or more but which had astigmatism less than 1 D on clinical examination. Exact measurement of the size of very small reflexes is more difficult than that of larger reflexes and the relative error is greater, resulting in false positive results. This is inherent in the method; however, particular care should be taken when measuring very small reflexes, especially if the pupils are different sizes in the two photographs.

Sensitivity using a vision-based screening method

Seventy-eight cases would have failed a screening test based on vision only (it is assumed that the case of refractive error and ptosis would have been identified), giving a sensitivity of 53.8%. The photorefractor is thus a more sensitive tool for screening than vision measurement alone.

Recommendations regarding a vision screening scheme

There is scope to improve the sensitivity of the method and some more work is required. From the data and the experience obtained in this study we have been able to develop recommendations regarding a future comprehensive screening scheme for three-year-old children, which could be established once the sensitivity is improved.

- Using presently available technology, the average time taken to reach a pass-or-fail decision is just over three minutes, assuming that the entire process is carried out at the kindergarten.
- Screening conducted at the kindergarten is likely to be ideal in terms of attendance rate and the reliability of the results obtained (**Table 6**).

Table 6. Screening rates, as a percentage of the number of families who signed informed consent forms, for the five participating kindergartens. Kindergarten A was not able to provide space and so the children were examined at the Hong Kong Polytechnic University.

	Kindergarten				
	A	B	C	D	E
No. of children screened	77	118	208	155	296
Attendance rate	66.4%	83.7%	89.7%	93.9%	95.8%

- The knowledge required for photorefraction screening is minimal, and the work is not complex. It should be done by a technician or equivalent. Appropriate training should be provided, especially with respect to identification of conditions such as strabismus, ptosis and media opacities.
- The equipment used in the study consisted of the photorefractor and the notebook computer, weighing

1.8 kg and 3.6 kg respectively. Together with other accessories, the total weight of the equipment needed is about 6 kg. The equipment is therefore easily portable.

- Based on 1999 costs, the cost of screening per child would be HK$23.90. This compares with HK$34.1 for the commercially available MTI screener.

Benefits of vision screening using a digital photorefractor

1. The sensitivity of photorefraction, as carried out in this study, was 71%, while that of vision screening was 54%.
2. Photorefraction is an objective method for measuring refractive error. It requires only minimal subject co-operation and does not require recognition of test characters (optotypes) or verbal skills.
3. Children are familiar with cameras and do not find the situation stressful, especially if the procedure is carried out in a familiar environment.
4. The skill required of the person carrying out the screening is less for photorefraction than for visual acuity measurement.
5. Photorefraction takes less time, in preschool children, than vision measurement.
6. Photorefraction is considerably more cost-effective using the digital photorefractor than using the MTI photoscreener.

Disadvantages of photorefraction as a screening technique

Although it is more sensitive than measurement of vision, there is, nevertheless, scope to improve the sensitivity of the method. It is important that the pupil size should be as large as possible.

Future work

Work should be carried out to improve the sensitivity of the digital photorefractor to low astigmatism. It would be useful to determine the photorefraction "dead zone" of the MTI photoscreener, as local ophthalmologists and optometrists may wish to purchase such an instrument, and the manufacturers do not indicate the range of refractive errors that can be identified by the instrument.

Conclusions

Validity of the digital photorefractor

The sensitivity and specificity of the digital photorefractor were 71.0% and 97.2%, respectively. Photorefraction, however, is considerably more sensitive than vision measurement, which had a sensitivity of 54%. The minimum pupil size which should be accepted as giving a valid result is 7 mm.

Recommendations regarding the cost and practicality of establishing a photorefraction screening service for Hong Kong preschool children

The photorefraction technique can be used successfully, even in children slightly below the age of three years.

Screening of three-year-old children is best undertaken in kindergartens because of a higher attendance rate.

The annual cost of a kindergarten-based digital photoscreening for three-year-old children would be HK$1,434,340 or HK$23.90 per child. The comparable cost per child of screening using the MTI, a commercially available portable photoscreener which uses Polaroid film, is HK$34.10 per child, 43% more than for digital photorefraction.

Prevalence of vision problems in Hong Kong children between the age of three and six years

Almost 11% of children had astigmatism of 1 D or more, 4.1% had hyperopia and only 1% had myopia at this age. Anisometropia was found in 1.6% and strabismus in 2.3%; 9.1% had habitual vision of less than 4/8 in one or both eyes.

Further information regarding the theoretical basis of photorefraction and the empirical calibration of the photorefractor used in this work is available from the authors. A breakdown of the estimated costs for digital photorefraction screening and for screening using the MTI is also available.

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