Reprinted from The Transactions of the Ophthalmological Society of New Zealand, Vol. 35, 1983, pages 43-49

RNZ 36

The Otago Photoscreener, A Method for the Mass Screening of Infants to Detect Squint and Refractive Errors

A. C. B. MOLTENO,[1] J. HOARE-NAIRNE,[1] J. C. PARR[1] ANNE SIMPSON,[1] I. J. HODGKINSON, N. E. O'BRIEN,[2] and S. D. WATTS,[2]
Dunedin

Abstract

The Otago photoscreener is a 35mm single lens reflex camera in which the flash light comes from a narrow ring around the outer margin of its lens. The margin is also the limiting aperture of the optic system, and in the centre there is a flickering fixation light. In a colour photograph taken at a distance of 0.5m of the face of a subject who is accurately focussing on and fixing the camera fixation light with both eyes, the fundus reflex in each pupil is absent or dark red and the corneal light reflexes are symmetrical. If either or both eyes are not appropriately focussed or fixing, the fundus reflex is brigher and yellow or white. Photoscreener photographs of 161 infants and children with normal acuity, reduced acuity and/or strabismus were assessed by independent observers without knowledge of the patients clinical status. This screening technique disclosed a sensitivity of 93 percent and specificity of 82 percent. It is a simple method applicable to routine screening of all one year old infants for impediments to normal visual development.

The relatively high incidence of squint and refractive error in infancy has led most developed communities to institute programmes for the detection of these conditions, at a stage when developmental amblyopia can be effectively treated. However, these programmes are not fully effective, due to the limitations of a cover test performed on young infants by paramedical personnel together with the difficulty of testing visual acuity in very young children. These difficulties have been partially overcome by Bruckner's light reflex test,[1,2] by Kaakinen's technique of photoretinoscopy[3,4,5] and by Howland's technique of photorefraction which has been used to investigate the refractive state and fixation pattern of young infants.[6,7,8,9] This communication describes the optical principles and performance of a photographic screener, which is designed for use in the field by community health nurses involved in the routine screening young children. The instrument is designed to be portable and hence sacrifices the quantitative indications of type and magnitude of the refractive error in favour of a sensitive indication of the presence or absence of squint or refractive error.

Principles of Photographic Screener

The three essential components of the photographic screener incorporated in a 35mm camera are:

(1) a light source consisting of a narrow annular reflector illuminated by an electronic flash tube;

(2) a custom-built photographic objective in which the first component of the lens is the limiting aperture of the system;

(3) a flashing fixation light placed exactly on the optic axis of the camera lens.

These components are assembled with the annular reflecting light- source surrounding and slightly overlapping the first component of the camera objective so that the inner sharp edge of the reflector forms the limiting aperture of the entire lens system. In addition, the first component of the lens is perforated, to permit the fixation light to be mounted on the optic axis and in the same plane as that occupied by the reflecting annulus. These components are mounted on a standard single lens reflex camera body with a focal plane shutter (Figs. 1 & 2). The xenon-filled flash tube used as a light source is driven by a mains operated portable power source, while the fixation light is driven by a circuit which provides a brief flash of light at 0.75 to 1.00 second intervals and at the same time drives a miniature speaker which emits a series of squeaks. This flashing light accompanied by a brief squeak serves to elicit fixed looking in the case of infants aged between 6 and 18 months and acts as an "interesting" fixation object for older children.

[1]Department of Ophthalmology, University of Otago
[2]Department of Physics University of Otago.

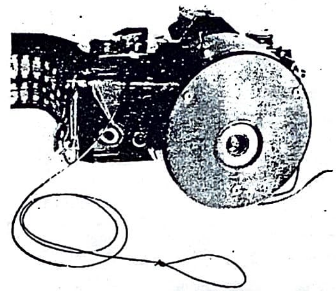

Fig 1. Photoscreener. Note the camera lens surrounded by an illuminated "slit" light source and the centrally placed flashing fixation light.

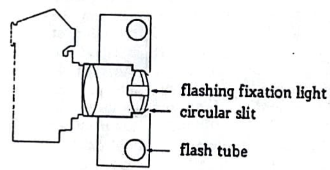

Fig 2. Diagram to show construction of photoscreener.

When this apparatus is used to photograph in colour the face of a subject, who is both emmetropic and fixing the flashing fixation target, the resulting picture shows symmetrically placed corneal reflexes and pupillary apertures which are either dark or show a dark red fundus reflex. However, eyes which do not fix the target show both a brightening and change of colour from deep red through yellow to white of the fundus reflex, together with displacement of the corneal light reflex with larger angles of deviation. Fixing eyes with significant refractive errors on the other hand, show brightening and colour change of the fundus reflex without displacement of the pupillary reflex. The reasons for the behaviour of the fundus reflex become clear if light is traced from the source through the subject's eye and back to the camera lens in the case of emmetropia, ametropia and deviation of the eye.

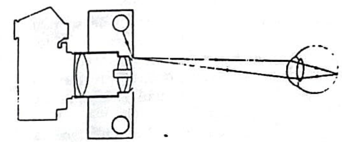

Fig 3. Diagram to show path of light from illuminated circular slit to sharply focussed image and back to circular slit in the case of a fixing emmetropic eye.

Emmetropia

In an emmetropic eye focussed on the fixation target, light from the annular reflector forms a sharply defined image of the annulus centred on the foveal pit. Light from this image is returned towards the pupil by:

(1) reflection from the vitreoretinal interface;

(2) scattering in the retina combined with reflection from Bruch's membrane;

(3) scattering within the retina and choroid combined with reflection from the sclera.

Light reflected from all 3 layers passes through the refractive system of the eye in the reverse direction and forms a set of 3 real images which are closely superimposed on the annular reflecting light source. The secondary image formed by light reflected at the vitreoretinal interface is formed by white light and is exactly superimposed on the reflector which prevents any of the light from entering the camera objective. Light that is reflected from Bruch's membrane is scattered laterally to some small degree, attenuated and coloured yellow by its double passage through the macular pigment and pigment epithelial layer. As a consequence, the image formed by this light is relatively dim and yellow in colour so that although the image slightly overlaps the inner edge of the annular reflector, the amount of light entering the camera objective is not sufficient to produce a yellow fundus reflex in the photograph of the subject.

Light reflected from the sclera undergoes a greater degree of lateral dispersion and is coloured deep red on passing twice through macular pigment, pigment epithelium and choroidal blood vessel layers. This red image is once more superimposed on the reflecting annulus but due to the lateral dispersion of the light in the retina and choroid, this image overlaps the inner (and outer) edge of the annular reflector sufficiently for a variable amount of red light to pass through the camera lens and focus on the film, where it is registered as a dull red fundus reflex in the pupils of blonde subjects and those with large pupillary apertures. In patients with deeply pigmented fundi and small pupils, this red fundus reflex is very dim or absent.

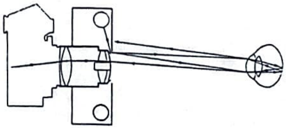

Fig 4. Path of light in hypermetropia with light reflected from superficial retinal surface and Bruch's membrane entering the camera lens.

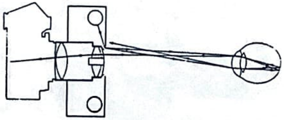

Fig 5. Path of light in myopia with light reflected from superficial retinal surface and Bruch's membrane entering the camera lens to cause brightening and change of colour of the fundus reflex.

Ametropia

In significant ametropia, whether myopia, hypermetropia or astigmatism, an out of focus real image of the annular reflector is formed in the retinochoroidal layers so that a large area of "retina" is illuminated, with shrinkage of the central non-illuminated portion when compared with an emmetropic eye (Figs. 4, 5). This enlarged, out of focus, real image in turn acts as a source for a series of secondary real images formed by white light from the vitreoretinal interface, yellow light from Bruch's membrane and red light from the sclera. The resulting series of secondary real images are both larger, in the sense of lateral spreading, than the original source and are focussed in planes other than that of the source. As a consequence, yellow and white light reflected by the more superficial retino-choroidal structures enters the camera objective and is focussed on the film plane to produce either a yellow (in the case of small defects) or white (in the case of larger defects) fundus reflex.

Deviation of the Eye

When an emmetropic eye does not accurately fix the fixation light, two processes are involved. In the first, off-axis abberations produce "enlargement" and defocussing of the primary image on the retina. This in turn leads to enlargement and defocussing of the secondary images so that yellow and white light can enter the camera lens. Secondly the illuminated ring of retina is shifted away from the region of macular pigment so that more light may be returned towards the pupil after reflection at Bruch's membrane and the inner layers of the sclera. These processes result in a corresponding brightening and whitening of the fundus reflex to an extent which depends on the angle of deviation and the distribution of the macular pigment. Thus on photographing an infant with this apparatus it is in theory possible to obtain the following information:

(1) an indication as to whether a refractive error or deviation of the optic axes is present or not from the colour and brightness of the fundus reflex;

(2) an indication of the direction and magnitude of any deviation of the optic axes from the position of the corneal reflexes;

(3) identification of a subject by a suitable label stuck to his or her forehead.

The general principle used in this test is simply that an optic system is "perfect" when light from a sharply defined source can be brought to a reflecting layer that is placed exactly at focus and returned to form an image which exactly matches the original source. Furthermore, if the light source has an opaque backing, light returned through the system will be blocked off if, an only if, the system is free from significant abberations.[10] In this application to a living eye, however, a single reflecting layer at the focus of the system is replaced by complex retinal and choroidal structures which show individual variations. Thus a clinical trial was undertaken to determine whether this type of apparatus would provide a useful screening test in practice.

Clinical Trial

One hundred and sixty one patients aged between 6 months and 10 years who were referred to the Department of Ophthalmology, Dunedin Hospital, for a variety of reasons were photographed with the photoscreening apparatus prior to clinical evaluation.

Photographic Technique

The subjects were identified by a gummed paper label on their foreheads and seated facing the camera with undilated pupils in subdued room light. The focus of the system was fixed at half a metre from the camera and as soon as the subject's face was in focus the operator attracted the child's attention by voice, switched on the flashing squeaking fixation light and operated the electronic flash. Kodak Ektachrome 500 ASA colour transparency film was used, developed in the usual manner and mounted for projection on a screen using a standard 35mm slide projector.

Clinical Evaluation

Clinical examination included a history, external examination, cover test and fundoscopy in all cases. This was supplemented as indicated by cycloplegic refraction and orthoptic assessment. Cases were classified retrospectively from the clinical notes into normal, borderline and abnormal groups using the following criteria to define the boundaries of each group.

Normal

(1) A corrected visual acuity of 6/6 or better in the worst eye and,

(2) orthophoria or mild heterophoria with good binocular vision (Fig. 6).

Borderline

(1) A corrected visual acuity of 6/6 to 6/9+ in the worst eye and/or,

(2) heterophoria, either marked with good binocular vision or moderate with some defect in binocular vision and including intermittent squint with well-developed binocular vision (Fig. 7).

Fig 6. Appearance of an emmetropic orthophoric infant showing uniformly dark red fundus reflexes with centrally placed corneal reflexes.

Fig 7. Appearance of a case of microstrabismus with 3 degrees of left esotropia and no refractive error. Right visual acuity is 6/5, left visual acuity 6/9+2. Note "borderline" brightening of left fundus reflex as compared to right.

Abnormal

(1) A corrected visual acuity of 6/9 or worse in the worst eye and/or,

(2) manifest strabismus including intermittent strabismus with poorly developed binocular vision and microstrabismus.

With these criteria the 161 cases were classified into a group of 48 clinically normal children, 37 clinically borderline children and 76 clinically abnormal children (Tables I and II, Figs. 8, 9, 10).

Photographic Classification

The criteria for photographic normality were:

(1) uniform deep red fundus reflexes of equal brightness in the two eyes;
(2) symmetrically placed corneal reflexes;
(3) equal pupillary sizes;
(4) absence of any visible defect such as ptosis.

The criteria for abnormality were:
(1) a yellow or white appearance to either or both fundus reflexes;
(2) deviation of the pupillary light reflex;
(3) definite inequality of pupillary size;
(4) any other visible defect.

Photographs of the children were classified withough knowledge of the clinical findings by three independent observers and sorted into the categories of normal, borderline and abnormal, using the majority decision for any cases of disagreement. The criteria for borderline status were uncertainty as to the presence of normal or abnormal features. This exercise resulted in 48 cases being classified as photographic normals, 29 cases being classified as photographically borderline and 84 cases being classified as being photographic abnormals (Figs. 6, 7, 8, 9 & 10).

Fig 8. Appearance of an infant with 4 dioptres of myopia in each eye showing bright white fundus reflexes.

Fig 9. Appearance of an infant with a right emmetropic eye with a dark red fundus reflex and a left eye one dioptre more hypermetropic showing a bright yellow fundus reflex.

Fig 10. Appearance of hypermetropic astigmatism. The refractive findings in this case were on the right a sphere of +1.25 with a cylinder of +1.75 at 55°; on the left side a sphere of +1.50 was present with a cylinder of +2.75 at an axis of 135°. The dark streaks crossing the pupil thus indicate the axis of each cylinder.

Results

The correlation between photographic and clinical classification is set out in Table I. From this it is evident that a case classified photographically as normal has a 0.83 probability of being classified as clinically normal, a 0.17 probability of being classified as clinically borderline and a very small (0 out of 48 cases) chance of being clinically abnormal. Similarly, a photographically borderline case has a 0.72 chance of being clinically borderline and a 0.10 probability of being clinically normal and a 0.17 probability of being clinically abnormal. Finally, a photographically abnormal case has a 0.84 probability of being clinically abnormal with a 0.09 probability of being clinically borderline and a 0.06 probability of being clinically normal.

Table I. Correlation between photographic and clinical classifications. N=161. The upper number in each box is the number of cases falling into each category while the lower number is the correlation between photographic and clinical classification for each category of cases.

	Photographic:	Normal	Borderline	Abnormal
	Normal	40 .83	3 .103	5 .06
Clinical	Borderline	8 .17	21 .724	8 .095
	Abnormal	0 .0	5 .172	71 .845

Table II. The main characteristics of photographic normal, borderline and abnormal groups.

Photographic:	Normal	Borderline	Abnormal
Corrected V.A. worst eye	4/4+	4/4– to 4/6+	4/6–
Muscle Balance	orthophoric	heterophoric	tropia
Spherical difference	0.5–D	0.5 to 1.25D	1.25+D
Astigmatic difference	1.0–D	1.0 to 1.5D	1.5+D

Discussion

From Table I it is evident that there is a moderate degree of scatter with overlap between photographic and clinical classification. A close scrutiny of the cases falling into each photographic classification revealed the following general characteristics (Table II).

Photographic Normals: This group includes children who are free from significant anisometropic errors, have myopia of less than 2 dioptres, hypermetropia of less than 5 dioptres and have well-developed binocular vision. In addition, all cases were essentially orthophoric and were sufficiently alert and co-operative to focus exactly on the fixation light.

Photographic Borderline Group: This group had in general a minor clinical abnormality. These were predominantly refractive errors of moderate degree with a significant difference in the visual acuities of the 2 eyes, or moderate to marked degrees of heterophoria. However, a small number of children had other defects including mental retardation and cerebral palsy.

Photographically Abnormal Group: These children showed the same pattern of defects to a more marked degree, with larger refractive errors, a considerable difference in acuity between eyes, poor binocular reflexes and marked heterophoria or manifest squint. In addition, cases of congenital cataracts, mental deficiency, ptosis, heterochromia iridis and melanosis oculi were identified.

Specificity of Photoscreening: A total of eight out of 161 children failed to look at the camera and were later identified as having central neurological deficits without any abnormality of their lower visual pathways. These cases, together with normal children who did not fix the fixation light when the photographs were taken, are technical failures and account for some of the 16 false positives in which children with normal eyes and lower visual pathways were classified as photographically borderline or abnormal. These 16 cases represent just under 10 percent of the total number screened.

Sensitivity of Photoscreening: So far the photoscreener has correctly identified as either borderline or abnormal 93 percent of the clinically borderline and abnormal group of cases. Furthermore, it has proved itself to be failsafe in the sense that a clinically abnormal case has not been classified as photographically normal. There is, however, a moderate amount of overlap between clinically borderline cases and photographic normals (and vice versa). This overlap due to uncertainties of photographic classification and/or uncertainties of clinical classification, particularly in the case of the younger children, involves 13 cases or 8 percent of the total sample.

In theory it is not possible for a clinically abnormal child to be classified photographically as normal except under 2 sets of circumstances. The first possibility is the case of a child in whom increased pigmentation of one fundus happened to compensate exactly for the change in colour and brightness of the fundus reflex produced by a unilateral refractive error of moderate degree (less than 2 dioptres). The second possibility would be a case of bilateral myopia of such a high degree (more than 12 dioptres) that the light reflected back towards the camera would be so widely dispersed that the fundus reflex would appear dark enough to mimic that of a normal eye. To avoid being detected as abnormal such a case would have to have parallel visual axes. If these very uncommon combinations of circumstances are excluded then a normal result on photoscreening indicates that the infant has the ability to focus both eyes sharply at the same time on the relatively simple (non-accommodative) target of a flashing light with accompanying squeaks. The performance of this visual task indicates that binocular vision is well developed and that the presence of significant amblyopia or refractive error can be excluded.

Potential as a Screening Device: The main conclusion drawn from this trial is that a single photograph taken with this photoscreener enables young children to be grouped as normals, borderline cases and abnormals, and that this photographic classification corresponds very closely with the clinical classification obtained by means of opthalmic examination, orthoptic workup and cycloplegic refraction. Thus if all infants were to be photoscreened at the age of approximately one year it would be possible to identify all those in whom visual development may be seriously defective at an age when treatment is most likely to be effective.

References

1. Bruckner R. Exakte Strabismusdiagnostik bei 1/2–3 jahrigen Kindern mit einim einfachen Verfahren, dem "Durchleuchtungstest". *Ophthalmologica* 1962; 144: 184–98.
2. Cibis-Tounge A, Cibis G W. Bruckner Test. *Ophthalmology* 1981; 88: 1041–1044.
3. Kaakinen K. A simple method for screening of children with strabismus, anisometropia or ametropia by simultaneous photography of the corneal and the fundus reflexes. *Acta Ophthalmol* (Khb) 1979; 57: 161–171.
4. Kaakinen K, Tommila V. A clinical study on the detection of strabismus, anisometropia or ametropia of children by simultaneous photography of the corneal and the fundus reflexes. *Acta Ophthalmol* (Kbh) 1979; 57: 600–611.
5. Kaakinen K. Photographic screening for strabismus and high refractive errors of children aged 1–4 years. *Acta Ophthalmol* (Kbh) 1981; 59: 38–44.
6. Howland H C, Howland B. Photorefraction: a technique for study of refractive state at a distance. *J. Opt. Soc. America* 1974; 64: 240–249
7. Braddick O J, Atkinson J, French J, Howland H C. A photorefractive study of infant accomodation. *Vision Res.* 1979; 19: 1319–1330.
8. Atkinson J, Braddick O J, Ayling L, Pimm-Smith E, Howland H C, Ingram R M. Isotropic photorefraction: a new method for refractive testing of infants. *Doc. Ophthal Proc.* Series 1981; 30: 217–223.
9. Braddick O, Ayling L, Sawyer R, Atkinson J. A photorefractive study of dark focus and refraction. *Vision Res.* 1981; 21: 1761–1764.
10. Hecht E, Zajac A. *Optics* Addison-Wesley Co Sydney 1974, 5th Imp. 1980; 478–481.