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The range of visual acuity using the crowded Kay Picture test and the range of refractive error present in children aged 42–48 months

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Abstract

Aims: **To establish, using the crowded Kay Picture test, the ranges of visual acuity in children aged 42–48 months which are associated with normal and abnormal refractive status. To identify the visual acuity and refractive error distribution in this age group.**

Methods: **Children attending a primary vision screening service had visual acuity measured and cycloplegic refraction undertaken. Refractive error was pre-defined as normal, borderline and abnormal by using existing evidence. On the basis of the refractive error found, visual acuity ranges associated with each refractive group were established. Children with squint and ocular pathology were excluded.**

Results: **Seven hundred and thirty-three children participated, with a median age of 43 months. Ninety per cent had a normal monocular refractive error. Ninety-three per cent of children had insignificant anisometropia. When anisometropia was insignificant, the median (IQR) visual acuity was 0.05 (0.00–0.10) for both right eye and left eye. Median (IQR) interocular visual acuity difference in this group was 0.025 (0.00–0.05). There was a statistically significant difference between the visual acuity ranges for each of the normal, borderline and abnormal refraction groups ($p < 0.001$). The median refractive error was +0.38D spherical equivalent for the right eye and +0.50D spherical equivalent for the left eye.**

Conclusion: **Children of 42–48 months with monocular visual acuity of equal to or better than 0.10 and with an interocular visual acuity difference of 0.05 or less when tested with the crowded Kay Picture test are likely to have a normal refractive status.**

Key words: Anisometropia, Crowded Kay Picture test, Refractive error, Screening, Visual acuity

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Introduction

Previous research has shown that pre-school children who fail to score 0.00 on visual acuity (VA) testing frequently turn out to have normal refraction. Shea and Gaccon[1] found that the mean monocular acuity for children with normal refraction was 0.20 in 3-year-olds and 0.14 in 4-year-olds, using the Keeler crowded logMAR test. Their cohort was new referrals to the orthoptic department. Sonksen *et al.*[2] tested a cohort of children between 2 and 8 years of age and produced centiles for monocular and binocular vision. Using the Sonksen logMAR test of VA, they found that 50% of children achieve monocular visual acuity of 0.10 or better by the age of 3½ years.

The crowded Kay Picture (KP) test[3] is widely used by orthoptists to measure VA in children of 3 years and above. When used at 3 metres, the test measures VA from 1.0 to −0.10, using a series of four pictures (two pictures for scores worse than 0.875) on each log level. As the test records VA logarithmically, scores above 1.0 can be accurately measured by reducing the test distance. There are currently no published data to indicate normal scores for any given age group. Jones *et al.*[4] compared the crowded KP test with the crowded logMAR letter test in children aged 2.5–16 years. They found a significant correlation between the VA results of the two tests, with a small, clinically insignificant, difference in the mean acuities. They found also that 70% of children below 5 years managed to perform the test successfully, compared with 60% managing the crowded logMAR test.

Guidance on prescription of glasses in children is variable and lacking in supporting evidence. An inability to recognise what constitutes 'normal' for a particular VA test and age group makes prescribing decisions more difficult still. The Spectacle Prescribing recommendations of the American Association for Pediatric Ophthalmology and Strabismus[5] suggest that members would correct, on average, 4.35DS of hyperopia, 2.67DS of myopia and 2.19DC of astigmatism in the 2- to 4-year age group, though these recommendations are based entirely upon members' personal experiences. The Royal College of Ophthalmologists' guidance[6] lists refractive

Table 1. Normal, borderline and abnormal groups for refractive error

	Monocular refraction		
	Normal	Borderline	Abnormal
Myopia	−0.25D to −0.75D SE	−1.00D to −1.75D SE	⩽−2.00D SE or MAM
Hypermetropia	0 to +2.75D SE	+3.00D to +5.25D SE	⩾+5.50D SE or MAM
Cylinder	⩽0.75DC	1.00DC to 1.75DC	⩾2.00DC
	Anisometropia		
	Insignificant	Borderline	Abnormal
	⩽0.50D SE or DC	0.75 to 1.75 SE or DC	⩾2.00D SE or MAM

SE, spherical equivalent; MAM, most ametropic meridian; D, dioptre; DC, dioptre cylinder.

errors that are 'thought capable of inducing amblyopia', but the list is not age-specific and is not supported by evidence.

Aims

The primary aim of the study was to identify, using the crowded KP test, the range of VA, both monocular and interocular difference, in children aged between 42 and 48 months which is associated with normal and abnormal refraction. The secondary aims of the study were to report the range of refractive error found in this age group and to identify which method of describing refractive error correlates best with VA. In addition, any effect on VA of gender or sequence of testing was sought.

Methods

In this study, cycloplegic refraction was used as the foundation from which to determine what is likely to be normal and subnormal VA with the crowded KP test. Refractive error was pre-defined as normal, abnormal and borderline (Table 1). These designations were evidence-based so far as strong evidence in the literature exists.[1,7-11] Otherwise, consideration was given to 'current practice' sources such as the American Academy of Ophthalmology Preferred Practice Pattern[12] and Royal College of Ophthalmologists' guidelines, as well as to personal experience. The aim was to define as securely as possible a level of refractive error highly unlikely to result in reduced VA (normal monocular refraction) and a level of refractive error highly likely to result in reduced VA (abnormal monocular refraction). As well as the likelihood of a symmetric reduction of acuity through ametropia, the likelihood of an interocular acuity difference due to anisometropia was also considered. By clearly demarcating normal from abnormal it was hoped to establish discrete ranges of VA associated with each.

Children participating in a community-based primary vision screening programme[13] in four south Derbyshire health centres were recruited to the study. The ethnicity of the children attending the health centres and eligible for recruitment was predominantly white British. A total of 772 eligible children were consented to the study in the period June 2008 to August 2009. Recruits were aged between 42 and 48 months, and had no known visual abnormalities, neurological impairment or severe developmental delay. The orthoptic component of the screening protocol comprised cover test at near and distance, ocular motility, convergence, prism fusion (20^{Δ}), and monocular VA using the crowded KP test. All children were tested by the same orthoptist. The order of VA testing (right eye/left eye) was randomised using stratified randomisation by health centre and the optometrist was blinded to the VA scores. The optometry component of the screening protocol, undertaken immediately following the orthoptic testing, comprised refraction under full cycloplegia (1% cyclopentolate) and ophthalmoscopy. Two optometrists participated in the study but only one of them performed the tests on each child.

Those children unable to understand the test requirements or unwilling to comply with monocular VA testing were withdrawn from the study ($n = 17$), as were children found to have heterotropia and/or ocular pathology ($n = 17$). A further 3 children were withdrawn because the parents decided not to proceed with cycloplegic refraction, 1 child due to a duplicate randomisation by mistake, and 1 because the study record was lost. Hence, in total 39 children were excluded following consent-taking. Children who were able to understand and perform the VA test but who showed, in the opinion of the orthoptist, a substantial lack of concentration for either one or both eyes were placed in a 'recheck' subgroup and asked to return for re-testing some months later ($n = 17$).

Statistical methods

The statistical analysis was performed using SPSS, 17.0. As the data were not normally distributed, the results were presented as medians (interquartile range, IQR). Refraction result was the net cycloplegic amount following an appropriate deduction for working distance. Refractive error in terms of spherical equivalent (SE) and most ametropic meridian (MAM) for each of right eye and left eye was analysed across the entire cohort. The Mann-Whitney *U*-test was used for comparing the VA and refractive errors between pairs of refraction groups (normal, borderline and abnormal), gender, testing sequence and optometrist. A comparative analysis was carried out without the scores from the re-check subgroup in order to eliminate what were probably unrepresentatively low scores. The Spearman correlation coefficient was used for testing possible correlations between VA and refractive error (SE and MAM). The specificity and negative predictive value (NPV) were estimated to differentiate the normal from the borderline

Table 2. Frequencies (%) of refractive error groups for right eye, left eye and anisometropia

	Normal	Borderline	Abnormal
Refractive error right eye	659 (89.9)	64 (8.7)	10 (1.4)
Refractive error left eye	660 (90.1)	61 (8.3)	12 (1.6)
Anisometropia	683 (93.2)	41 (5.6)	9 (1.2)

groups as their VA ranges overlapped. Specificity is defined as the probability of a child with normal monocular refraction being identified correctly by the KP test as having VA in the normal range, and NPV as the probability of a child categorised as having a VA score in the normal range having a normal monocular refraction.

Results

A total of 733 eligible children were included in the analysis. Forty-eight per cent of participants were male and the median age was 43 months (range 42–44 months). Three hundred and seventy-three (50.8%) children were randomised to right/left eye order of VA testing and 361 (49.2%) to left/right eye order. Seventeen children (2.3%) were placed in the re-check subgroup due to substantially reduced concentration affecting one or both eyes, with 12 of them showing a larger than expected interocular difference in VA. The frequency of monocular refractive error was similar for both eyes and is shown, along with the frequency of anisometropia, in Table 2.

Monocular visual acuity in the presence of insignificant anisometropia

In order to exclude the influence of anisometropic amblyopia on a monocular VA score, only those children designated as having insignificant anisometropia were included in this part of the analysis ($n = 683$). VA of both eyes was found to be significantly different between each of the normal, borderline and abnormal refraction groups (Table 3). Removing the re-check cases from the normal monocular refraction group left the median VA and IQR for both eyes unchanged. With re-checks removed from the borderline monocular refraction group, the median and IQR changed slightly (Table 3). Most clinically significant was the reduction by two pictures in the 75th percentile for the right eye. VA remained significantly different among the three groups with the re-checks excluded.

The value 0.10 appeared in the IQR of both the normal and borderline groups. The specificity of the KP test was higher and the NPV was almost the same, however, when the cut-off value 0.10 was included as the 75th percentile of the normal group, rather than the 25th percentile of borderline, thus differentiating the two groups (Table 4).

Table 4. Specificity (%) and negative predictive value (%) (95% confidence interval) for two scenarios, with and without re-checks, in children with insignificant anisometropia ($n = 683$); the 75th percentile of the normal VA range is (a) 0.075 and (b) 0.10

	Specificity for 0.075	Specificity for 0.10	NPV for 0.075	NPV for 0.10
Right eye	69 (65–73)	80 (77–83)	98 (97–99)	97 (96–99)
Left eye	70 (66–74)	80 (77–83)	98 (96–99)	97 (95–98)
Right eye without re-checks	70 (66–73)	81 (78–84)	98 (97–99)	98 (96–99)
Left eye without re-checks	71 (67–74)	81 (78–84)	98 (96–99)	97 (95–98)

NPV, negative predictive value; VA, visual acuity.

Table 5. Median (IQR) interocular visual acuity difference for anisometropia groups

Insignificant anisometropia	Borderline anisometropia	Abnormal anisometropia
($n = 683$)	($n = 41$)	($n = 9$)
0.025 (0.00–0.05)†*	0.125 (0.05–0.175)*	0.725 (0.20–0.91)

†$p < 0.001$ versus borderline group; *$p \leqslant 0.001$ versus abnormal group.

There was no significant difference in VA between males and females (for right VA, $p = 0.627$; for left VA, $p = 0.406$). Furthermore, there was no significant difference in VA according to which eye was tested first (for right VA, $p = 0.629$; for left VA, $p = 0.404$).

Interocular visual acuity difference

The interocular visual acuity difference (IOVAD) was significantly different among the three groups of insignificant, borderline and abnormal anisometropia (Table 5). With the re-check cases removed from the group with insignificant anisometropia (leaving $n = 673$) the median IOVAD and IQR were unchanged. With re-checks removed from the borderline group (leaving $n = 39$), the median IOVAD dropped from five to four pictures, i.e. 0.10 (0.05–0.175). There were no re-checks in the abnormal group. The IOVAD remained significantly different among the three groups without the re-checks ($p \leqslant 0.001$).

Table 3. Median (IQR) visual acuity for right and left eye, with and without re-checks, in children with insignificant anisometropia ($n = 683$)

	Normal monocular refraction	Borderline monocular refraction	Abnormal monocular refraction
Right eye	($n = 635$)	($n = 42$)	($n = 6$)
	0.05 (0.00–0.10)†*	0.20 (0.10–0.325)*	0.56 (0.425–0.71)
Left eye	($n = 632$)	($n = 44$)	($n = 7$)
	0.05 (0.00–0.10)†*	0.19 (0.10–0.27)*	0.40 (0.35–0.60)
Right eye without re-checks	($n = 624$)	($n = 38$)	($n = 6$)
	0.05 (0.00–0.10)†*	0.19 (0.10–0.28)*	0.56 (0.425–0.71)
Left eye without re-checks	($n = 621$)	($n = 40$)	($n = 7$)
	0.05 (0.00–0.10)†*	0.16 (0.10–0.25)*	0.40 (0.35–0.60)

†$p < 0.001$ versus borderline group; *$p < 0.001$ versus abnormal group.

Table 6. Median (IQR) refractive error in SE and MAM for each eye

	SE	MAM
Right eye	+0.38D (0.00 to +1.00D)	+0.50D (0.00 to +1.25D)
Left eye	+0.50D (0.00 to +1.00D)	+0.50D (0.00 to +1.25D)
p value of right vs left eye	0.164	0.144

SE, spherical equivalent; MAM, most ametropic meridian; D, dioptre.

Table 7. Correlation of VA with SE and MAM for each eye in children with insignificant anisometropia ($n = 683$)

	SE vs VA in whole group	**MAM vs VA in whole group**
Right eye	$r = 0.101$, $p = 0.008$	$r = 0.124$, $p = 0.001$
Left eye	$r = 0.009$, $p = 0.018$	$r = 0.117$, $p = 0.002$
	SE vs VA in abnormal group	**MAM vs VA in abnormal group**
Right eye	$r = 0.760$, $p = 0.011$	$r = 0.700$, $p = 0.024$
Left eye	$r = 0.676$, $P = 0.016$	$r = 0.643$, $p = 0.024$

VA, visual acuity; SE, spherical equivalent; MAM, most ametropic meridian; *r*, Spearman correlation coefficient.

Distribution of refractive error and association with optometrist and visual acuity

Refractive error described in terms of SE and MAM for each right eye and left eye was analysed across the entire cohort (Table 6). There were no significant differences in SE and MAM between the left and right eye. Eighty-three per cent of children were tested by optometrist A and 17% by optometrist B. The refractive errors found by each of them were statistically significantly different ($p < 0.001$), with optometrist B finding a median of 1.13D higher in SE for right eye and 0.87D higher for left eye. Nevertheless, the 5th to the 95th percentiles of SE (−0.63D to +2.63D) for both optometrists lay within the normal refraction boundaries, i.e. −0.75D to +2.75D. As the normal refraction group contained 90% of the children, it seems appropriate to accept this difference as being of clinically low significance. There is no clear explanation for this difference in findings, although the median age of children tested by optometrist A was statistically significantly lower than that of those tested by optometrist B (42 (42–43) vs 44 (43–45) months, $p < 0.001$).

To isolate the effect on VA of ametropia from that of anisometropia, only those children with insignificant anisometropia were included ($n = 683$). This analysis showed that, across the entire cohort, both SE and MAM were significantly positively correlated with VA for both eyes, though the correlations were clinically weak (Table 7). Within each of the normal and borderline refraction groups there was no correlation with VA, while in the abnormal group ($n = 22$) VA was significantly positively correlated, statistically and clinically, with both SE and MAM (Table 7; Figs. 1 and 2).

Abnormal refraction

Only 1.4% of right and 1.6% of left eyes had an abnormal monocular refraction and in 1.2% of cases there was abnormal anisometropia. In the 13 eyes with abnormal monocular refraction in the presence of insignificant anisometropia, the median VA was 0.56 for right eye and 0.40 for left eye. In total, 22 eyes had abnormal refraction. Ignoring astigmatism $\leqslant 0.75$DC, the commonest refractive errors were complex hypermetropic oblique astigmatism (27%) and complex hypermetropic astigmatism with the rule (27%) (Fig. 3). The greatest hypermetropic ametropia was 6.25D SE and 7.25D MAM, and the greatest myopic ametropia was 2.50D SE and 3.00D MAM.

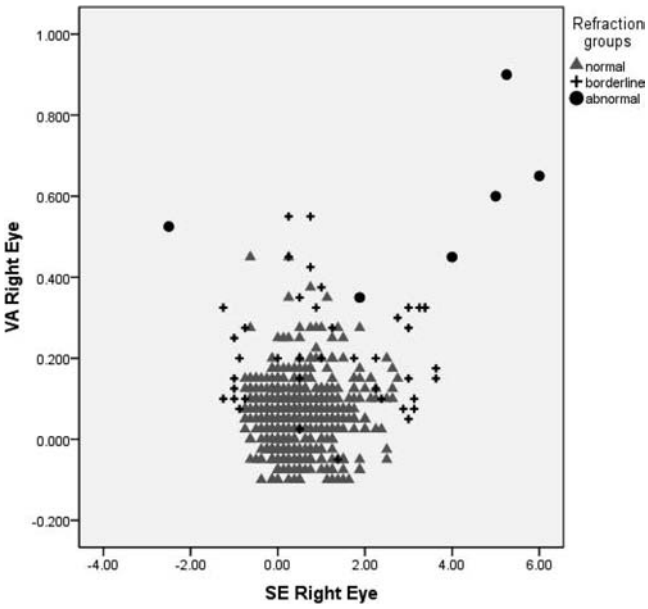

Fig. 1. Correlation of VA with SE for right eye in children with insignificant anisometropia ($n = 683$). VA, visual acuity; SE, spherical equivalent.

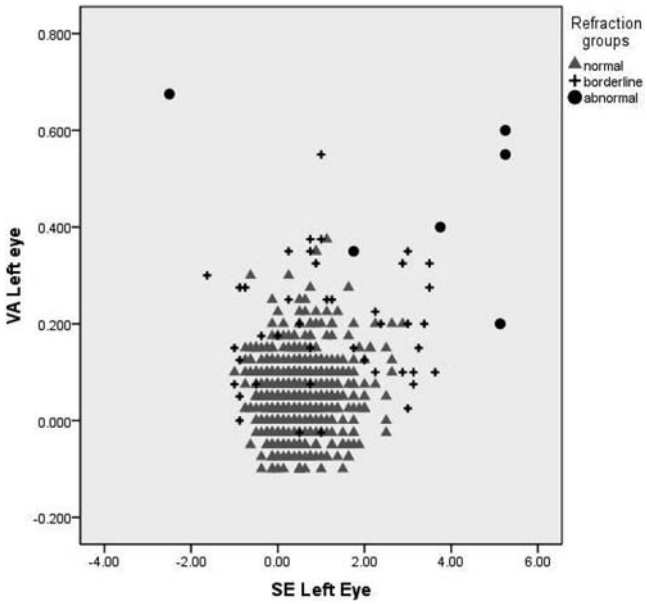

Fig. 2. Correlation of VA with SE for left eye in children with insignificant anisometropia ($n = 683$). VA, visual acuity; SE, spherical equivalent.

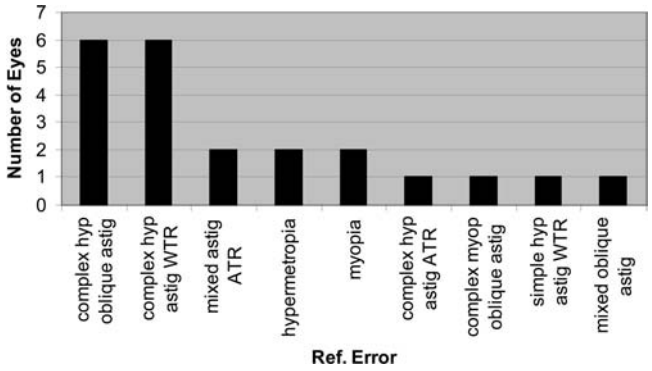

Fig. 3. Distribution of abnormal monocular refractive error* ($n = 22$). Hyp, hypermetropia; myop, myopia; astig, astigmatism; WTR, with the rule; ATR, against the rule.
*For astigmatism $\leqslant 0.75$DC, the error is reported as a sphere only.

Discussion

Compared with much of the existing literature on VA in pre-school children, this study has two main advantages: first, the subjects came from a primary population, thus representing a group with minimal selection bias; second, every VA measurement was accompanied by a 'gold standard' cycloplegic refraction. By considering the refractive error as an independent statistic, and designating it as normal, abnormal or borderline, a range of monocular VA associated with each group was identified. Similarly, by designating anisometropia as insignificant, abnormal or borderline, a range of IOVAD associated with each group was identified.

On the basis of the designated refractive groups, 89.9% of right eyes and 90.1% of left eyes had a normal monocular refraction and 93% of children had insignificant anisometropia. Children with a normal monocular refraction had a median monocular VA of 0.05 and a median IOVAD of 0.025 (i.e. one picture) with the crowded KP test. Monocular refraction was borderline in 8.7% of right eyes and 8.3% of left eyes, with a median monocular VA score close to 0.20. Anisometropia was borderline in 6% of cases, the median IOVAD being 0.125 (i.e. five pictures). Only 1.4% of right and 1.6% of left eyes had an abnormal monocular refraction and in 1.2% of cases there was abnormal anisometropia.

Although the VA ranges associated with each of the three monocular refraction groups were statistically significantly different from one another, there is a degree of overlap between the normal and borderline refraction groups. For example, a child scoring 0.10, which falls within the IQR for both normal and borderline monocular refraction, could potentially have hypermetropia between +0.25DS and +5.25DS according to the refractive error definitions applied. However, the two groups were distinguished by better specificity and similar NPV results when the cut-off value of 0.10 was included as the upper limit in the normal VA range. Using the KP test in a screening setting, the clinician may decide refraction, or at least re-checking, is warranted for children scoring more than 0.10, with an expectation that some false positive results will be generated. Further study incorporating a complete sensitivity and specificity analysis would be useful. A larger number of abnormal cases is required to estimate sensitivity accurately.

Both the commonly used methods for describing refractive error, spherical equivalent and most ametropic meridian, correlated with VA, albeit rather weakly. This is unsurprising. While in general VA is expected to decline as ametropia increases, a given refractive error will produce a range of VA scores rather than a single score, particularly for hypermetropia. This was illustrated clearly here by the lack of intra-group correlation in the two largest groups of normal and borderline. This means that, for example, within the normal group a given VA score was as likely to be associated with a refraction of −0.75DS as with one of +2.75DS, which seems entirely reasonable given that this range of refraction is designated as normal. What is notable is that the correlation overall between MAM and VA was slightly stronger than that between SE and VA, suggesting that use of MAM might give a better prediction of VA.

Conclusion

In this cohort, taken from the general population, 90% of children aged between 42 and 48 months had a normal monocular refractive status and 93% had insignificant anisometropia. The conclusion is that a developmentally normal child in this age group, without strabismus, is likely to achieve a monocular acuity of 0.10 or lower and an IOVAD of 0.05 or less when tested with the crowded KP test. In the presence of an abnormal refraction, a child is likely to achieve a monocular VA of 0.35 or higher and/or an IOVAD of 0.20 or greater. The test is able to accurately differentiate children with normal and abnormal refractive status. Differentiation between normal and borderline refractive status is less clear-cut and clinicians must be prepared for some false positive results if the test is used in a screening setting.

In this study the refractive status was pre-defined. Whilst an evidence-based approach to this process has been taken, inevitably opinion on what constitutes normal and abnormal refraction will differ. It is hoped that this study adds to the evidence base of what constitutes normal and abnormal VA for this age group using the crowded KP test.

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