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Normative Visual Acuity in Infants and Preschool-aged Children in Sydney

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Keywords: Visual acuity, Preschool children, Population-Based, ATS HOTV EVA, Teller acuity cards II, LogMAR VA

Abstract

Purpose: To provide population-based normative visual acuity (VA) by age, in children participating in the Sydney Paediatric Eye Disease Study aged 6 to <72 months.

Methods: Monocular VA was measured using the Amblyopia Treatment Study (ATS HOTV) protocol (24-<72 months). Some children were also tested using linear ETDRS or HOTV logMAR VA charts (30-<72 months). If unable to perform recognition acuity, the Teller Acuity Cards II (TAC II) was performed (6-<42 months). Children with significant refractive error or ocular disease were excluded.

Results: Improvement in VA with age was shown on all three vision tests (all $p < 0.0001$). Mean VA using ATS HOTV ($n=836$) was 0.13 logMAR (6/8) at <36 months, which improved to -0.01 (6/6) at 66-<72 months. Mean ETDRS/HOTV ($n=399$) VA was 0.26 logMAR (6/11) at <36 months, which improved to 0.1 (6/7.5) at 66-<72 months. Mean monocular TAC II ($n=442$) was 5.7 cycles/degree (0.72 logMAR) at 6-<9 months and improved to 12.4 cycles/degree (0.38 logMAR) at age 30-<33 months. Associations with ATS HOTV VA included, prematurity ($p=0.027$) and socio economic status (SES) factors such as home ownership ($p=0.039$) and employment of one ($p=0.019$) or both parents ($p=0.003$).

Conclusions: VA norms in children, improved with age and were different according to the VA test used. Low SES was associated with poorer VA, supporting the need for test specific VA norms to be established for different populations. The ATS HOTV appears to be the best test to use for vision screening due to its lower false positive referral rate.

Accurate and reliable visual acuity (VA) assessment is the basis for diagnosis and management of ocular conditions in people of all ages. Since the development of standardised optotypes by Snellen, normal adult VA has been accepted as equal to 6/6 (Duke-Elder 1968). Population-based studies in older adults (aged >50 years) suggest that mean VA is 6/6 or slightly worse, as VA tends to decline with age (Klein et al. 1991; Attebo et al. 1996; Rubin et al. 1997; Taylor et al. 1997; McKean-Cowdin et al. 2010). Studies in younger adults (>40 years) show that mean VA in this age group can be better than 6/6 (Elliott et al. 1995; Lovie-Kitchin & Brown 2000; Hazel & Elliott 2002; Ohlsson & Villarreal 2005), but such levels of VA are typically not achieved until a child is at least 9 years, particularly if an adult VA linear chart is used for testing (Simons 1983; Robaei et al. 2006; Dobson et al. 2009).

As yet, there is currently no known gold-standard vision test for preschool aged children. Normative VA levels in younger children must be determined to accurately set referral criteria for vision screening and to effectively monitor and manage eye conditions. This normative VA should be ascertained according to both the particular vision test and the age of the child. In addition, VA norms need to be both population-based and to exclude those with sight-affecting ocular conditions, to ensure measures accurately reflect what could be expected as normal VA in healthy eyes. Not all studies reporting normal VA for age in children fulfil this criterion (Drover et al. 2008; Friedman et al. 2008; Vision In Preschoolers (VIP) Study Group 2010).

Additionally, population-specific norms may need to be established, given that there are potential effects of ethnicity (Friedman et al. 2008) and socio-economic status (Robaei et al. 2005; Pan et al. 2009), on the level of VA measured. Population-based studies, such as that by Pan et al (2009) have reported normative data using the

single surround HOTV vision test in African American and Hispanic preschool children in Los Angeles, but these may not be appropriate to use as VA norms for other locations, with different levels of socio-economic status and ethnic groupings.

There are no studies that have examined normative VA in preschool age children using the adult gold-standard linear EDTRS (or using HOTV letters) logMAR chart, and only one study reporting VA norms in older children aged 6-7 years using this chart (Robaei et al. 2005). The single surround HOTV vision test (Holmes et al. 2001; Moke et al. 2001) is increasingly being used in research protocols (The Pediatric Eye Disease Investigator Group 2002) and has a high testability in preschool aged children (Cotter et al. 2007; Leone et al. 2012) but does not have established VA norms in populations other than African American and Hispanic children in the United States.

In this paper we determined the normative VA of children aged 6 months to 6 years in a population-based sample in Sydney, Australia, with a predominantly European Caucasian population and also a significant proportion of children of East Asian and South Asian origin. Three age-appropriate standardised tests were used, the Amblyopia Treatment Study (ATS) HOTV protocol, the EDTRS or equivalent linear logMAR chart using HOTV optotypes and matching card, and for pre-verbal children, the most recent edition of the Teller Acuity Cards (TAC) II.

Methods

Participants

The Sydney Paediatric Eye Disease Study (SPEDS) is a population-based survey of eye health in children aged between 6 and 72 months in Sydney, Australia. Postal codes were randomly selected from the inner, middle and outer Sydney regions to ensure a representative sample. Detail of the enumeration sampling have been previously reported (Leone et al. 2012). A total 2462 of these children (73.8% participation rate) were examined during 2007-9. This study was approved by the Human Research Ethics Committee of the University of Sydney, and adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from the parent or guardian of each study participant before examinations.

Procedures and Visual Acuity Assessment

Questionnaires completed by parents, provided data on the ethnicity of the child, based on the self-identified ethnic origin of both parents, using ethnic categories of European Caucasian, East Asian and South Asian, consistent with the Australian Standard Classification of Cultural and Ethnic Groups (Australian Bureau of Statistics 2005). All children were placed into a mixed ethnicity category labeled 'Other' where the ethnic group was >10% of the population, or there were children with parents of differing ethnicity. Ethnicity breakdown of children for the outer region was 65% European Caucasian, 8.6% East Asian, 12% South Asian, and 14% 'Other'. Due to similar ethnic and SES distributions the inner and middle regions were combined for analysis and the ethnic breakdown of this combined region was 21%, 36.8%, 14.7%, and 27.4% respectively. The median household income was high for the outer region (AUD 74,672 p.a.) (Australian Bureau of Statistics 2006). The 'more inner' regions

were combined for statistical analysis with the middle region encompassing two postcodes which had a median household income of AUD 41,808 p.a. and 40,456 p.a., and the inner region had a median household income of AUD 58,292 p.a. (Australian Bureau of Statistics 2006).

All children underwent a comprehensive examination performed by orthoptists and medical doctors trained in the study's protocol, which was based on that of the Multi-Ethnic Pediatric Eye Disease Study (MEPEDS) (Varma et al. 2006) and the Baltimore Pediatric Eye Disease Study (BPEDS) (Friedman et al. 2008).

Examinations included VA, ocular motility, cycloplegic refraction (cyclopentolate hydrochloride 1% or 0.5% in children <12 months, and tropicamide 1%) measured using a hand-held Retinomax autorefractor (Nikon Corporation, Tokyo, Japan), and/or the Canon RK-F1 autorefractor (Canon, Tokyo, Japan) or streak retinoscopy.

Monocular VA was attempted in all children aged ≥ 24 months using the ATS protocol (Holmes et al. 2001), that presents single-surround HOTV letters on the electronic visual acuity (EVA) tester (Moke et al. 2001) at 3m (Jaeb Center for Health Research, Tampa, FL). High contrast black letters on a white background (98% contrast) were presented on a 17" CRT monitor (IBM C170 Thinkvision), with luminance calibrated to 85-105 candelas/m². VA scores were provided in 0.1 logMAR increments from 1.6 (6/240) to -0.1 (6/5).

If children aged ≥ 30 - <60 months had good concentration, and matching skills as demonstrated when being tested on the ATS HOTV, they also performed VA testing using a standardised retroilluminated (luminance of 85cd/m², 100% contrast) linear logMAR chart (2.44m, CSV-1000, VectorVision Inc., Dayton, OH) with either the high contrast ETDRS or HOTV test plates. However, all children ≥ 60 months attempted the ETDRS or HOTV logMAR chart as well as the ATS HOTV. The VA

testing order was not randomised in order to capture testability and threshold VA levels for children performing the ATS HOTV to be comparable with the examination protocol of MEPEDS (Pan et al. 2009) and BPEDS (Friedman et al. 2008). The ETDRS or HOTV logMAR chart testing protocol used a staircase technique (Stewart et al. 2006), to refine threshold VA and our methodology has been described previously (Leone et al. 2012).

The Teller Acuity Cards II (Stereo Optical Co. Inc., Chicago, IL) (McDonald et al. 1985) was used to assess VA in all preverbal children, ≥ 6 to < 24 months, according to the manufacturer handbook (Teller et al. 2005), but without a stage (Clifford-Donaldson et al. 2006). Luminance was kept above 10 candelas/m² by utilising overhead diffuse fluorescent lighting and a spotlight directed towards the ceiling, in addition, the contrast of the cards are approximately 60-70% (Teller et al. 2005). In children ≥ 24 to < 42 months who were unable to perform any of the recognition tests, VA was assessed using the objective Teller Acuity Cards II. Testing was conducted binocularly and then monocularly. Reliability of the testing was also noted during testing.

VA was assessed on a second day if either eye was $< 6/12$ or an intra-ocular difference of ≥ 0.2 logMAR (or ≥ 1 octave for TAC II) and no associated pathology or significant refractive error, or if poor co-operation on VA testing was noted. The eye with the worse VA was tested first on re-test, and the best VA recorded in each eye over the two VA assessments was used as the final VA.

Exclusion criteria

There were a total of 1058 (42.9%) children with one or more of the following exclusion criteria, unable or unreliable VA measures (n=36), outside of the age limitations (n=299), or incomplete refraction or fundus examination data (n=180).

Spherical equivalent refractive error (SER) in either eye was defined as ≤ -0.50 dioptre (D) (n=120) or $> +3.00$ D (n=138) or astigmatism ≥ 1.00 DC (n=429), anisometropia ≥ 1.00 D (n=46), or antimetropia ≥ 1.00 D in the hyperopic eye (n=3), or children with strabismus (n= 76), nystagmus (n=9) or ocular media or retinal disorders (n=21) or those reporting a previous condition, such as treated amblyopia (n=38).

Statistical Analysis

The threshold ATS HOTV VA for right and left eyes were highly correlated (Pearson's correlation=0.79, $p \leq 0.0001$), thus right eye VA were used to report monocular normative VA. Testability of the ATS HOTV and ETDRS or HOTV logMAR charts for children ≤ 60 months have been previously reported (Leone et al. 2012).

Testability of the binocular and monocular TAC II is reported as a percentage for the total population of children tested. A child was considered testable only if they were able to perform the test in both eyes monocularly, if the child was unable to perform the test in either eye monocularly then they were not considered testable for monocular TAC II. Binocular testability includes children that were able to perform the TAC II test with both eyes open. TAC II data were transformed to a \log_{10} scale for analysis but reported in cycles per degree (cyc/deg) with standard deviations and interocular acuity differences analysed in an octave or \log_2 scale. Prediction limits (Whitmore 1986) were reported for TAC II (formula for 95% prediction limits:

$$mean \pm t_{\frac{\alpha}{2}} \left(\left(\sqrt{1 + 1/n} \right) \times SD \right)$$

with $t_{\frac{\alpha}{2}}$ = two-tailed value from the Student's t distribution, SD = Standard deviation, and n = number of subjects in each age group).

Mean VA, 95% confidence intervals and standard deviations are stratified by age. Age related VA improvements were tested using linear regression. Examination of false positive rates of referral for age groups were tested using criteria of $\leq 6/12$ and $\leq 6/15$ in children less than 48 months, as these cut-offs have been used in similar paediatric studies (Multi-ethnic Pediatric Eye Disease Study 2008; Friedman et al. 2009). Ethnic differences in VA were assessed after controlling for age using a general linear model.

Interocular VA differences and associations with age were examined using the logistic procedure and Wald chi-squared test. ATS HOTV was used for analysis of risk factors for VA using multi-variable linear regression. The β – coefficient and overall model r^2 along with the p-value for each predictor is reported. SAS software version 9.2 was used for all analyses (SAS Institute, Cary, North Carolina, USA).

Results

Of the 2462 children who participated in the SPEDS study, 1404 children met the inclusion criteria for this analysis, and were predominantly of European Caucasian ancestry (Table 1). Using the ATS HOTV (n=836, Table 1), VA distributions appear to narrow and the peaks shift towards 0.0 logMAR (6/6) with increasing age (Figure 1a). Mean VA improved progressively with age ($r^2 = 0.2275$, $p < 0.0001$) (Table 2). After controlling for age, there was no significant gender difference in mean VA using the ATS HOTV ($p = 0.12$). Children of East Asian ethnicity had significantly worse mean VA when using the ATS HOTV (0.07 logMAR, 95% CI 0.06-0.08) than children of European Caucasian ethnicity (0.04 logMAR, 95% CI 0.04-0.05) (Table 2). Most children achieved equal vision in both eyes (74%), and an inter-ocular difference of ≥ 1 VA line was not associated with age ($p = 0.3$).

Socio economic factors such as home ownership ($p = 0.039$), and employment of one ($p = 0.019$) or both parents ($p = 0.003$) were significantly associated with VA in analyses that controlled for age, ethnicity and gender (Table 3). Children in the outer region with higher household income had significantly better mean VA (0.04 logMAR [95% CI, 0.03-0.04] adjusted for age) than children in the 'inner' regions with lower household income (0.07 logMAR [95% CI, 0.06-0.07]).

Prenatal and neonatal factors such as prematurity ($p = 0.02$), and NICU admission ($p = 0.03$) were significantly associated with poorer VA, after adjustment for age, only prematurity ($p = 0.03$) remained significant after further adjustment for ethnicity and gender (Table 3). Maternal smoking during pregnancy was significantly associated with better vision in our normative population after adjusting for age, gender and ethnicity ($r^2 = 0.29$, $p = 0.04$). However, when performing the same analysis

on the whole population including those with ocular conditions, maternal smoking during pregnancy was no longer significant, after adjusting for age ($r^2=0.12$, $p=0.1$).

The distributions of VA using the linear ETDRS or HOTV logMAR charts are shown in Figure 1b. The peaks appear to narrow and shift towards 0.1 logMAR (6/7.5) with increasing age. The mean VA improved progressively with age ($r^2=0.21$, $p<0.001$) (Table 4). After controlling for age variations, there were no significant ethnic differences in VA when measured using the linear ETDRS or HOTV logMAR charts ($p=0.4$). Most children (92%) achieved equal vision in both eyes (defined as <1 line difference) and age was not associated with an inter-ocular difference of ≥ 1 VA line ($p=0.3$).

There were 544 children who met the analysis criteria and were initially tested binocularly using the TAC II (Table 1), with a high testability rate at all ages (94% of 971). When tested monocularly ($n=442$) the TAC II had lower testability (76% of 968). Testability was higher in children below 12 months ($\geq 85\%$) than in children ≥ 12 months ($\geq 65\%$). The distributions of VA using the TAC II monocularly (Figure 2) appeared to narrow and the peaks shifted and improved towards 13.00 cyc/deg (0.36 logMAR) with age. Mean binocular VA was better than mean monocular VA in all age groups (Table 5). As a cut-off for normal VA, the lower prediction limit sets the criteria for abnormal VA for age, please refer to Table 5 for age related breakdowns. There were significant improvements in mean binocular and monocular VA with age ($r^2=0.29$, $p<0.0001$, $r^2=0.32$, $p<0.0001$, respectively) (Table 5). After controlling for age, there were no significant ethnic differences in VA using TAC II monocularly ($p=0.3$) or binocularly ($p=0.5$). Most children achieved equal vision in both eyes (83%), and age was not associated with an inter-ocular difference of ≥ 0.5 octave (≥ 1 card difference) of VA ($p=0.7$).

Mean VA using the common unit of measure, the minimum angle of resolution (MAR) measured by all tests, from ages 6 to 72 months is presented in Figure 3. Vision rapidly improved with age in children less than 24 months, followed by a period of less rapid improvement, approaching a VA of 6/6 at age 60 months when tested using the ATS HOTV. VA measured using the ETDRS or HOTV logMAR chart was significantly different from ATS HOTV, and was approximately 1 line different across all ages (Figure 3).

If a typical VA cut-off for referral of $\leq 6/12$ (0.3 logMAR) was uniformly applied to our population of preschool children without any ocular disease or condition, using the ATS HOTV for children in the age groups 48-<60 months and 60-<72 months would give 0.4% false positive referral rate for both age groups. However, using the ETDRS or HOTV logMAR chart would give 6% and 3.4% false positive rates for respective age groups. Using the ATS HOTV in the younger age groups <36 months and 36-<48 months, the same cut-off would give a 5% and 2.5% false positive rate respectively. Using the ETDRS or HOTV logMAR chart the false positive rate rises dramatically to 50% and 19% respectively.

If a more conservative cut-off for referral of $\leq 6/15$ (0.4 logMAR) is applied for children <48 months of age, using the ATS HOTV in the age groups <36 months and 36-<48 months, this cut-off would create a 0% and 0.9% false positive referral rate respectively. In the same age groups, using the ETDRS or HOTV logMAR chart the false positive rate rises to 16.7% and 5.3% respectively.

Discussion

This paper is the first to report VA norms from a population-based sample of predominantly European Caucasian preschool-aged children. The strongest factor associated with VA was age with improvements noted with increasing age for all VA tests used; TAC II, ATS HOTV and the linear ETDRS or HOTV logMAR chart. Gender was not associated with VA norms using ATS HOTV in this sample, as has been reported elsewhere (Pan et al. 2009), but ethnicity and SES were.

The greatest rate of VA improvement occurred in children aged <24 months, measured using the TAC II. Studies in young infants using both preferential acuity and visual evoked potentials have shown even more rapid improvement in VA from birth to 8 months of age, with slower improvements thereafter (Norcia & Tyler 1985; McDonald et al. 1986; Courage & Adams 1990; Mayer et al. 1995; Salomao & Ventura 1995). These phases of rapidly improving VA may reflect anatomical and physiological development of the eye and visual pathway, including an increase in the density and maturation of the retinal cones (Hirsch & Hylton 1984; Yuodelis & Hendrickson 1986), and myelination of optic nerve fibres (Magoon & Robb 1981). The appearance of adult-like levels of vision (6/6) at 60 months of age when using the ATS HOTV, coincides with completion of myelination of the optic fibres (age 54-66 months) (Magoon & Robb 1981), and maturation of the fovea, which has been shown to occur sometime after age 45 months (Yuodelis & Hendrickson 1986).

Ethnicity was associated with VA in our study using the ATS HOTV. Despite children of East Asian ethnicity demonstrating higher rates of testability on VA tests (Leone et al. 2012), they had statistically significant lower mean VA than children of European Caucasian, South Asian or the grouped category of 'Other' ethnicities. This difference was equivalent to 1.5 letters, which is of minor clinical significance. In a

similarly predominantly European Caucasian population of young children, derived from a hospital setting in the USA and tested using the ATS HOTV, the VA norms across the comparable age range of 3-6 years were very similar to those of our population (Drover et al. 2008). However, when our VA norms are compared to those from the predominantly African American and Hispanic children in MEPEDS (Pan et al. 2009), where no inter-ethnic difference was observed, the age norms in our whole population are consistently close to 1 line better than those established in the MEPEDS population. If further compared to only children of European Caucasian ethnicity in our study, the difference in VA in comparison to those of the children from MEPEDS increased to 1.5 lines (0.15 logMAR) in the youngest age groups and nearly 1 line (0.08 logMAR) in the oldest age group.

The reasons for the difference in VA norms using the ATS HOTV between our study and MEPEDS are not entirely clear. We used a higher cut-off for significant hyperopia (+3.00 DS) compared to MEPEDS (+2.00 DS), but this would have caused our VA norms to be potentially worse, rather than better than MEPEDS, although we do know that hyperopia has less impact on VA in children than myopia (Leone et al. 2010; O'Donoghue et al. 2012). Ethnic differences in the distribution of VA in a population-based sample without exclusion of ocular conditions, have also been observed when comparing whites and blacks in the BPED study in Baltimore (Friedman et al. 2008), using the same VA protocol.

In our study, all SES factors, such as home ownership and the employment status of parents were significantly associated with VA using ATS HOTV, with poorer VA associated with lower SES markers, such as 'no home ownership'. Additionally, lower mean VA was found in the more 'inner' geographical regions of our study, which also had lower mean household income and a greater proportion of

children of East Asian ethnicity, compared to the outer region. MEPEDS (Pan et al. 2009) also found an association of a higher percentage of children with poorer VA amongst families with low income. They also reported that 65% of parents in the MEPED study had an annual income <\$USD 20,000, which is approximately half the median annual income of our lowest SES region (\$AUD 40,456) examined. It is possible that variation in SES may underpin the differences in VA norms found between ethnic groups in our study and the VA distributions in BEPEDS (Friedman et al. 2008), and may contribute to other differences between studies. The exact mechanisms involved in the association of low SES with poorer VA are unknown.

Other factors that were related to poorer VA norms using the ATS HOTV in children included gestational and peri-natal factors such as prematurity and NICU admission. Conversely, maternal smoking during pregnancy was related to slightly better VA in our population of children without ocular conditions. However, when analysis was performed on the entire SPEDS population including those children with ocular pathology and refractive error, maternal smoking was found to be a risk factor for visual impairment (Pai et al. 2011).

The VA norms for age in our study when tested with the ATS HOTV were approximately 1 line better in comparison to the linear ETDRS or HOTV logMAR chart. We have previously reported that where both tests were performed by the same children at ages ≥ 60 months, this 1 line difference was also consistently evident (Leone et al. 2012). This difference is consistent in other studies comparing different optotype tests in young children (Rice et al. 2004; Stewart et al. 2006; Leone et al. 2012). It could be assumed that the adult gold standard linear chart is correctly measuring VA, and that the ATS HOTV is overestimating VA. However, the ATS HOTV conforms to the principles of optotype design as set out by Snellen (Snellen

1862) and has appropriately spaced crowding bars for the detection of amblyopia (Flom et al. 1963; Stager et al. 1990). VA obtained using the ATS HOTV is therefore testing the minimum separable detail that can be recognised and represents a correct determination of a child's VA (Brown 2004). As the ATS HOTV was always tested first, it could be argued that the overall poorer VA associated with the ETDRS or HOTV logMAR chart may be due to fatigue. Conversely, it could be argued that the learning effect due to familiarisation with testing procedures may have improved VA measures on the ETDRS or HOTV logMAR chart. Regardless, when only the ETDRS or HOTV logMAR chart was used in children aged 6 years in the Sydney Myopia Study (Robaei et al. 2005), the mean VA was 6/7.5 after excluding children with refractive error. This mean VA using the ETDRS or HOTV logMAR chart was not significantly different to the mean VA scores obtained with our SPEDS sample of a similar age (≥ 66 months). This suggests that the VA differences between tests and overall improvement in VA with age may be due to cognitive, rather than the visual, capabilities of the child. It is likely that presenting the single optotype within clear boundaries (or 'in the box') allows the child to confidently and unambiguously identify the test optotype, whereas lines of optotypes on a chart are more confusing for the preschool aged child.

When using a typical referral cut-off value of $\leq 6/12$ VA for vision screening, our results clearly show that there is a greater false-positive rate when using the ETDRS or HOTV logMAR chart in comparison to using the ATS HOTV. This false positive rate is greatest in the younger children less than 4 years of age. When using a more conservative cut-off of $\leq 6/15$ in this younger age group, the false positive rate fell, but still remained higher for the linear ETDRS or HOTV logMAR chart than the

ATS HOTV. This suggests that the ATS HOTV would be the more suitable test for screening and clinical assessment in preschool aged populations.

We are unable to make comparisons of the VA norms we have established in children aged <5 years as there are no other population based studies using the ETDRS or HOTV logMAR charts in this age group that have also excluded those children with ocular conditions. For the older children, aged 5-6 years, however, the mean linear VA of 0.1 logMAR found in our study is consistent with mean linear VA established in the Sydney Myopia Study younger sample, mean age 6.7 years (Robaei et al. 2005), and others (VA means: 0.04-0.16 logMAR) (Dobson et al. 2009; Hargadon et al. 2010).

While there have been previous reports of VA norms for the TAC in this age group (McDonald et al. 1986; McDonald et al. 1986; Courage & Adams 1990; Mayer et al. 1995; Salomao & Ventura 1995; Spierer et al. 1999), this is the first from a population-based sample using TAC II. Our norms are slightly lower than those reported by Vistec for the original TAC (Courage & Adams 1990; Salomao & Ventura 1995). However, they are consistent with the recommendation to lower TAC II norms by approximately 0.5 octaves (Clifford et al. 2005; Megumi et al. 2006) when using previously published TAC norms.

Conclusions

We have demonstrated that VA improves with age, most dramatically in the first 24 months of life, followed by a consistent phase of slower improvement continuing up to 72 months and likely beyond. These aged-specific population-based VA norms should assist in defining referral criteria for VA in preschool vision screening protocols. As test-dependent variation in VA was observed in this age

group, these criteria need to be test-specific. For accurate ongoing assessment of VA, clinicians need to set new VA baselines when progressing to a more adult-standard vision test as a child cognitively matures. Low SES of parents had a negative impact on their child's VA, which did not appear to be related to parental education or reading to the child. This may also be the basis of ethnic differences in VA, though this needs further investigation. This factor, along with variation of normative values of VA with age according to the test used, suggests that there is a need for similar studies to be conducted to establish VA norms within other specific populations. Our study confirms that the ATS HOTV is a suitable test in this age group for vision screening due to its high testability (Cotter et al. 2007; Leone et al. 2012) and the low false positive rate established in these preschool children without any ocular conditions.

Acknowledgements

Funding/Support: This study was supported by grant 402425 from the National Health & Medical Research Council of Australia; and National Health and Medical Research Council Biomedical (Dora Lush) postgraduate research scholarship 457173 (Ms Leone).

Role of the Sponsors: The sponsoring institutions had no role in the design and conduct of the study; in the collection, management, analysis and interpretation of the data, or in the preparation, review, or approval of the manuscript.

Financial disclosure: None for all authors

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Table 1: Demographics of Normative Population by Vision Test

	Total	ATS HOTV	ETDRS/HOTV LogMAR Chart	TAC II	
				Binocular	Monocular
	n=1404	n=836	n=399	n=544	n=442
Mean age (range, months)	38 (6-<72)	51 (24-<72)	57 (30-<72)	18 (6-<42)	18 (6-<42)
	n (%)	n (%)	n (%)	n (%)	n (%)
Females	631 (45)	398 (47.6)	195 (48.9)	225 (41.4)	188 (42.5)
European Caucasian	685 (49)	422 (50.5)	194 (48.6)	241 (44.3)	210 (47.5)
East Asian	258 (18)	160 (19.1)	82 (20.6)	98 (18.0)	81 (18.3)
South Asian	178 (13)	105 (12.6)	54 (13.5)	73 (13.4)	53 (12.0)
Other	283 (20)	149 (17.8)	69 (17.3)	132 (24.3)	98 (22.2)

Table 2: Mean ATS HOTV in logMAR units, by Age and also by Ethnicity

	n	Mean Acuity (95% CI)	SD	Mode Acuity (Snellen Equiv. metres)
Age (months)				
<36	97	0.13 (0.11-0.15)	0.08	0.1 (6/7.5)
36-<42	109	0.09 (0.07-0.10)	0.09	0.1 (6/7.5)
42-<48	127	0.07 (0.05-0.09)	0.11	0.0 (6/6)
48-<54	115	0.05 (0.03-0.06)	0.08	0.0 (6/6)
54-<60	143	0.03 (0.02-0.04)	0.07	0.0 (6/6)
60-<66	109	0.01 (0.00-0.03)	0.07	0.0 (6/6)
66-<72	136	-0.01 (-0.02-0.00)	0.07	0.0 (6/6)
Ethnicity				
	n	Mean Acuity (95% CI)		
European Caucasian	422	0.04 (0.04-0.05)	-	-
East Asian	160	0.07 (0.06-0.08)	-	-
South Asian	105	0.04 (0.03-0.06)	-	-
Other	149	0.04 (0.03-0.06)	-	-

Table 3: Risk factors adjusted for age, and adjusted for age, ethnicity and gender for vision testing using the ATS HOTV

Associated Factors	Adjusted	Adjusted for Age, Ethnicity and		
	for Age	Gender		
	P value	β coefficient	R ²	P value
Not reading to child	0.1	0.01	0.28	0.2
Preschool attendance	0.6	-0.004	0.29	0.5
Parental tertiary education (University)	0.05	-0.01	0.29	0.054
Parental tertiary education (Technical College)	0.15	-0.01	0.29	0.26
Home ownership	0.016	-0.01	0.30	0.039
Employment of one parent	0.02	-0.03	0.29	0.019
Employment of both parents	0.002	-0.03	0.29	0.003
Prematurity <37 weeks	0.02	0.02	0.30	0.027
NICU admission	0.03	0.02	0.29	0.078
Low birth weight <2500g	0.05	0.03	0.31	0.058
Fed Infant formula	0.7	0.00	0.30	0.9
Maternal alcohol consumption during pregnancy	0.07	-0.01	0.32	0.3
Maternal smoking during pregnancy	0.008	-0.02	0.29	0.042

Table 4: Mean Linear ETDRS/HOTV LogMAR Chart in logMAR units, by Age

Age (months)	n	Mean Acuity (95% CI)	SD	Mode Acuity (Snellen Equiv. metres)
<36	24	0.25 (0.20-0.30)	0.11	0.3 (6/12)
36-<42	22	0.22 (0.17-0.26)	0.10	0.2 (6/9.5)
42-<48	35	0.16 (0.14-0.18)	0.06	0.2 (6/9.5)
48-<54	43	0.15 (0.12-0.18)	0.10	0.1 (6/7.5)
54-<60	67	0.13 (0.11-0.14)	0.07	0.1 (6/7.5)
60-<66	84	0.13 (0.11-0.14)	0.07	0.1 (6/7.5)
66-<72	124	0.11 (0.10-0.12)	0.07	0.1 (6/7.5)

Table 5: Mean VA for Binocular and Monocular Teller Acuity Cards II by Age with 95% prediction limits.

Age (months)	Binocular			Monocular		
	n	Mean Acuity	SD	n	Mean Acuity	SD
		(cyc/deg) (95% prediction limits)	(octaves)		(cyc/deg) (95% prediction limits)	(octaves)
6-<9	81	6.33 (3.57-11.20)	0.41	73	5.72 (2.78-11.76)	0.52
9-<12	84	6.43 (3.25-12.74)	0.49	76	5.58 (3.03-10.27)	0.44
12-<15	63	6.74 (3.48-13.05)	0.47	47	5.98 (2.89-12.39)	0.52
15-<18	61	7.34 (2.88-18.71)	0.67	41	6.56 (2.82-15.23)	0.59
18-<21	53	7.57 (3.27-17.53)	0.60	38	7.54 (3.64-15.61)	0.51
21-<24	53	9.02 (3.95-20.60)	0.59	40	7.37 (3.46-15.67)	0.53
24-<27	45	10.96 (4.67-25.72)	0.60	32	10.71 (4.27-26.86)	0.64
27-<30	43	12.08 (4.53-32.22)	0.69	39	9.71 (3.76-25.09)	0.67
30-<33	26	12.80 (4.53-36.20)	0.71	25	12.41 (4.35-35.43)	0.72
≥33	35	12.60 (5.53-28.73)	0.58	31	11.81 (5.04-27.70)	0.59

Figure Legends

Figure 1a: Normal population distribution of vision by age group using the Amblyopia Treatment Study (ATS) HOTV Electronic Visual Acuity (EVA) Tester

Figure 1b: Normal population distribution of vision by age group using the linear ETDRS or HOTV logMAR chart (CSV1000).

Note: Distributions for LogMAR results were based on a rounded value of 0.1.

Figure 2: Normal population distribution of visual acuity by age group using monocular Teller Acuity Cards II

Figure 3: Development of normal mean monocular visual acuity for all vision tests in minimum angle of resolution units (MAR) (** Note: SD were large and not informative, Figures 1 to 3 and Table 2,4 and 5 were used to portray the variation or consistency of scores*)

Inset: Normal mean visual acuity for linear ETDRS or HOTV logMAR chart and the Amblyopia Treatment Study (ATS) HOTV Electronic Visual Acuity (EVA) Tester in logMAR units, with 95% confidence intervals.

Figure 1a: Normal population distribution of vision by age group using the Amblyopia Treatment Study (ATS) HOTV Electronic Visual Acuity (EVA) Tester

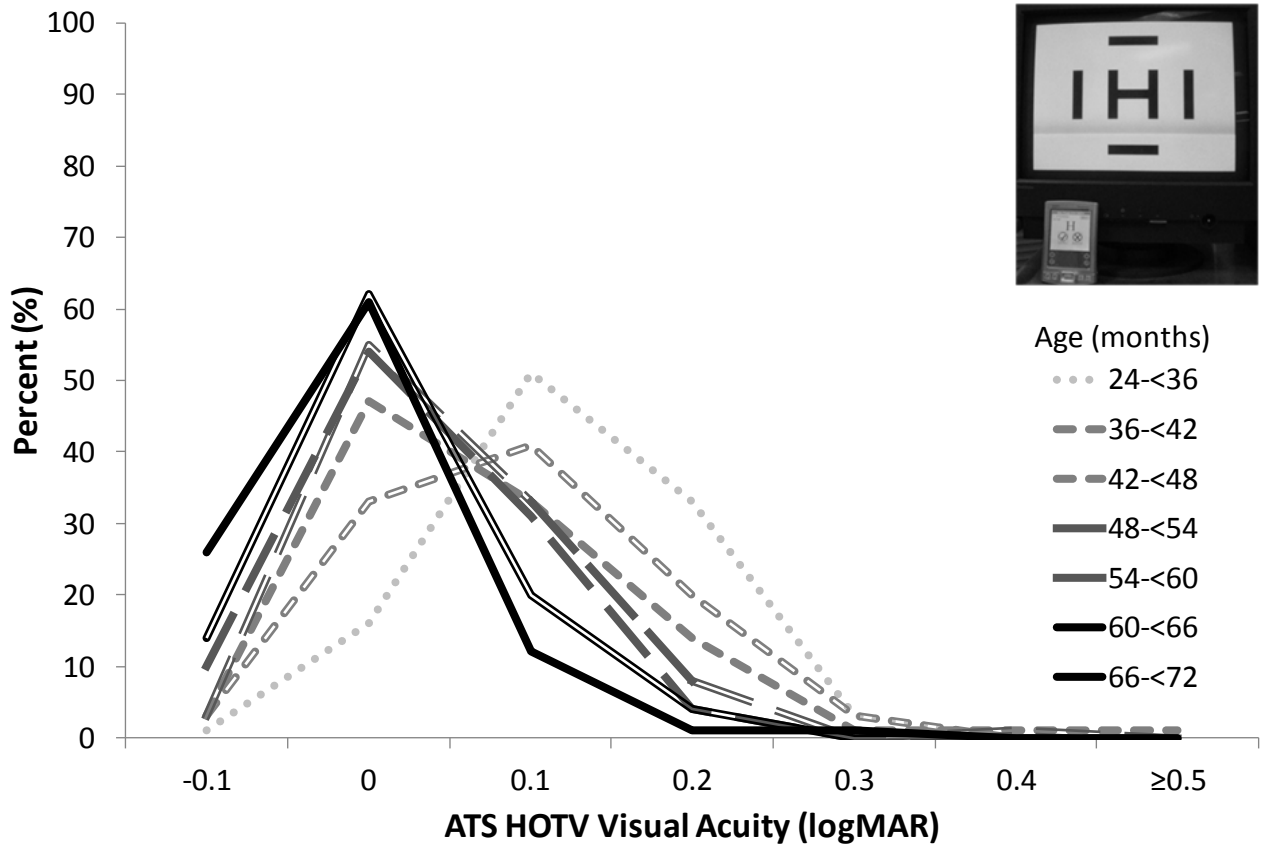


Figure 1b: Normal population distribution of vision by age group using the linear ETDRS or HOTV logMAR chart (CSV1000).

Note: Distributions for logMAR results were based on a rounded value of 0.1.

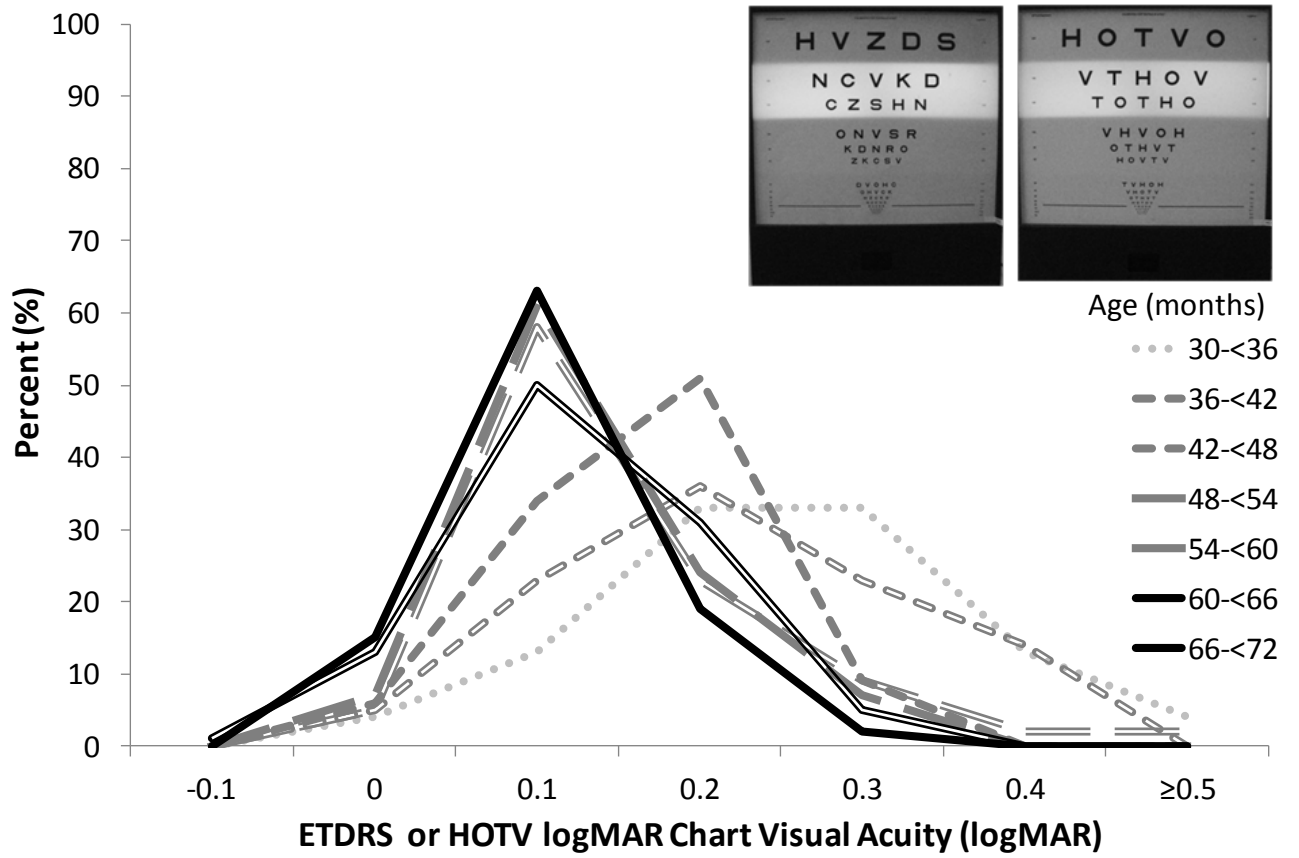


Figure 2: Normal population distribution of visual acuity by age group using monocular Teller Acuity Cards II

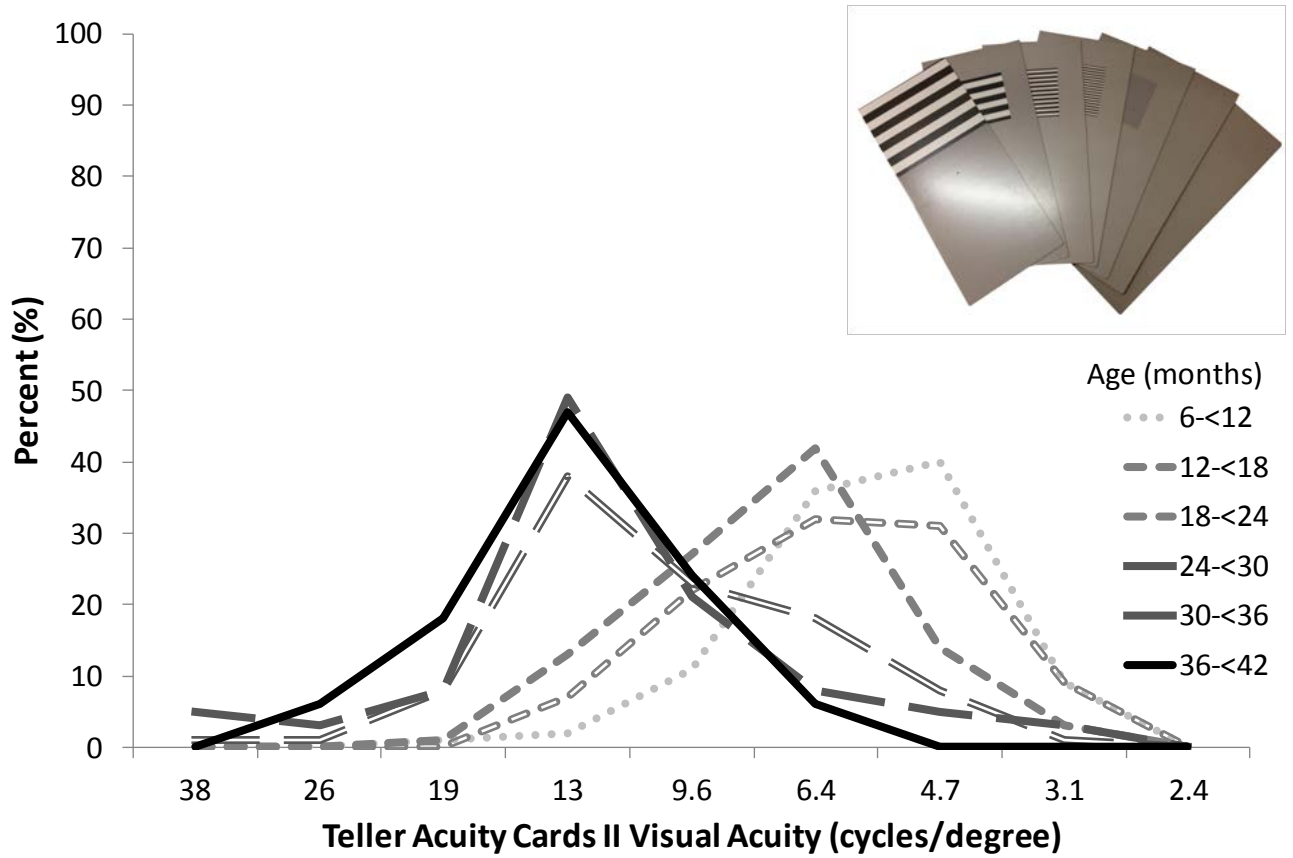


Figure 3: Development of normal mean monocular visual acuity for all vision tests in minimum angle of resolution units (MAR) (* Note: SD were large and not informative, Figures 1 to 3 and Table 2,4 and 5 were used to portray the variation or consistency of scores)

Inset: Normal mean visual acuity for linear ETDRS or HOTV logMAR chart and the Amblyopia Treatment Study (ATS) HOTV Electronic Visual Acuity (EVA) Tester in logMAR units, with 95% confidence intervals.

