Research Square

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Contribution of Age, Acuity and Cognition to the Development of Visual Function

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Research Article

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Abstract

Purpose. Visual function continues to develop throughout childhood, yet clinical norms are based almost exclusively on chronological age. Since many visual tests require adequate visual acuity or impose a cognitive demand, age may not always be the optimal predictor of visual development. This study examined whether visual acuity or cognitive ability are better predictors of selected visual functions than age in typically developing children.

Methods. This cross-sectional study assessed the predictive value of age, visual acuity (logMAR), and cognitive ability (Raven's Coloured Progressive Matrices) for a range of visual functions in 85 typically developing children aged 5–11 years. Partial correlations were used to determine the best predictor for each measure, controlling for the remaining variables.

Results. Age was the strongest independent predictor of near point of convergence and Groffman Visual Tracing score. Visual acuity was the strongest predictor of contrast sensitivity, vergence facility, and refractive error. Cognitive ability was the strongest predictor of form and motion coherence thresholds. Positive fusional vergence, accommodative amplitude, and accommodative facility did not correlate significantly with any of the three predictors.

Conclusion. Visual development during childhood is not solely age-dependent. For several higher-level visual functions, visual acuity and cognitive ability are stronger independent predictors than age. These findings suggest that clinical norms based on age alone may be insufficient, and that acuity- and cognition-stratified normative data should be considered, particularly for children with developmental disorders.

Introduction

There is substantial research evidence to suggest that visual function improves developmentally over the school age years [1-8]. The causes of this development, however, are less clear. Three main explanations have been proposed to explain these changes: 1) maturational cortical changes [9]; 2) improvements in visual acuity [10] and 3) changes in cognitive ability [11]. While each of these potential mechanisms have been shown to contribute to improvements in vision, it remains unclear which factor best explains these changes and whether some visual factors are more affected by one change than another.

This study aimed to determine whether developmental changes in vision, including higher-level visual function are better predicted by age, visual acuity or cognitive ability. No previous study has directly compared age, acuity, and cognition as competing predictors across a broad battery of visual tests. This distinction is critical since current clinical norms are based primarily on age. If visual function is better predicted by cognitive ability or visual acuity than age, these norms will have to be revised to prevent over- or under-referral of children with visual deficits.

Methods

This cross-sectional study assessed the relationships between age, visual acuity, cognition and multiple measures of visual function in typically developing children.

Participants

We recruited 90 children; 15 typical children each from kindergarten (5.0 and 6.0 years of age) and school grades one to five (6.5 to 11.0 years of age: F: 53%, M: 47%).

Children were excluded from the analysis if they were born prematurely, had a developmental disorder or had low acuity in both eyes. In addition to the five children excluded due to these causes, four children were excluded because of under-correction of more than -0.25DS (spherical equivalent) for measurements of distance acuity. This cut-off point was chosen because acuities was tested at three meters, and an error of -0.25DS will not interfere with this, whilst -0.50DS will. Conversely, it is unlikely that small amounts of myopia would have a negative impact on functional and other measures of vision performed at close distances. Thus, data from 81 children (42 female, 39 male) were included in the analysis of the typical clinical tests (see below), and 85 children were included in all other analyses if not reported otherwise. The population has been described in full elsewhere. [11]

Parental consent was obtained from caregivers after receiving an explanation of the study in writing. Verbal assent was given by children. The study was approved by the regional ethics committee for medical research at the University of Oslo and followed the tenets of the Declaration of Helsinki.

Clinical tests

This study used a range of tests typically included during a clinical exam along with tests of visual function and other tests of vision that have been used as part of research studies. The visual tests included are shown in Table 1. All tests were administered in accordance with test instructions.

Table 1 Tests of vision by category.

Acuity & Refraction Tests	Accommodation & Vergence Tests	Higher Visual Function Tests
Presenting visual Acuity at 3m (Lea Chart)	Near point of convergence	Developmental Eye Movement Test
Contrast sensitivity	Vergence facility	Groffman Visual Tracing Test
Dry Retinoscopy at 6m	Positive fusional vergence	Form coherence
	Accommodation amplitude	Motion coherence
	Accommodation facility	

Acuity and Refraction Tests

Contrast sensitivity: The Bailey-Lovie 6 m low contrast acuity chart was chosen due to the close relationship with the Lea logMAR acuity chart. Only the worse eye as determined by LH acuity, was tested in this study. Children read the first letter of each row and, if the first letter was misread, they were asked to read the whole of the previous row.

Since the Bailey-Lovie test requires literacy, seven of the youngest children who were unable to perform this test were excluded from this analysis.

Test of Refraction

In this study, refraction was measured by dry retinoscopy performed by a skilled optometrist and is expressed as mean SE (Spherical Equivalent) refractive error of both eyes. Dry (non-cycloplegic) retinoscopy was used rather than cycloplegic refraction, as cycloplegia was considered likely to adversely affect children's performance on the subsequent functional visual tests. Readers should note that this may result in an underestimation of the true hyperopic refractive error, particularly in younger children, and this is acknowledged as a limitation of the study.

Tests of Accommodation and Vergence

Measurements indicated as “near” were performed at 40 cm unless otherwise noted.

Near point of convergence (NPC): A Wolff wand (silver sphere) was used to determine the “break point” for convergence. The near point was recorded as the distance (in cm) from the child’s eyes on the last of three consecutive trials to reduce possible ceiling effects.

Positive fusional vergence: The same wand was also used as a fixation object to measure positive fusional vergence with a prism bar at near.

Vergence facility: A 12 PD (Prism diopter) base out / 3 PD base in “flipper” and a stereoscopic near vision acuity vectogram were used to record vergence facility (in cycles per minute: CPM). Children were instructed to say when they were able to see all vectogram lines through polarized goggles. At this point, the prism flipper was turned, and the practitioner waited till the child’s eyes had adjusted to be able to see all the lines again. This was repeated for 30 seconds, and each positive reply was counted. Vergence facility was recorded in cycles per minute (CPM) from the number of single flips in 30 seconds. Children with poor binocular vision, e.g., strabismus, obtained a score of zero on this test, thus creating a floor effect.

Accommodation facility: This followed the same procedure as vergence facility using a +/-2.00 DS flipper and a 20/32 acuity line on a near vision chart to be seen clearly enough for the letters to be discerned.

Tests of Higher Visual Function

Developmental eye movement (DEM) test: This test provides information about saccadic eye-movements used for reading [13] and was performed using the standardized procedure. Score was calculated as the ratio of the time needed to read 80 unevenly spaced horizontal digits divided by the time needed to read the same evenly spaced vertical digits. Higher values for this ratio indicate that children have poorer control of their horizontal eye movements.

Groffman visual tracing (GVT) test: This tests the child's ability to sustain visual attention, and has been found to correlate with reading ability [14]. Children were presented with a practice plate in which two "spaghetti lines" connected a letter with a number. They were asked to trace the line using their eyes only and to state the number connected with each letter. When the practice assessment was passed successfully, a test plate with five similar lines reaching from letters A - E to numbers 1 - 5 was presented. The child traced the spaghetti line from each letter and reported the number to which this was connected. For each letter, if the correct response was provided within 16 seconds, a full score of 10 points was awarded. Scores were gradually reduced with 1 point awarded if more than 60 seconds were needed to complete the task, or 0 if not completed. Total number of points, (0 -50) was used as the outcome measure.

Form and Motion Coherence

Measures of threshold form- and motion coherence performance were made using the random dot kinematogram (RDK) "Varying proportion" test and the Form coherence test, which have both been used previously in reading research [15-17].

Motion coherence tests: The RDK test was used to measure the length of time for which a stimulus was required to be present to detect coherent movement. Children were instructed to look at a white cross in the middle of a computer screen while simultaneously observing two panels with moving dots. Each panel was created using 100 grey dots with a radius of 4 points and a contrast level of 4.0% moving at 20º per second against a black background. Each dot had a life span of 60 milliseconds.

In one panel, 100% of the dots moved in a coherent direction while in the other panel the dots moved randomly. The child was asked to pick the box in which the dots moved coherently. Choice of left or right panel was made by the examiner pressing one of two alternate keys on the computer keyboard. With each trial, the time for which the stimulus was present was decreased.

The viewing time at which coherent motion was reliably detected was used to calculate a threshold for the time needed to integrate global motion across the coherently moving dots.

Form coherence tests: The Form coherence test also had two panels to choose from, with one panel containing a proportion of lines oriented in the same direction while the other panel showed randomly oriented lines. The child was asked to look at each panel and point out the panel with the highest proportion of lines oriented in the same direction. The task was not timed but both panels disappeared from the screen after three seconds.

For the first sample panels, all lines were in coherently oriented in one panel and randomized in the other. Gradually, the proportion of coherently oriented lines was reduced until a wrong response was given and a new cycle started at an easier level. The outcome measure was the minimum percentage of coherently oriented lines needed to discern the correct panel.

Cognitive Assessment

A test of cognition (Raven's Colored Progressive Matrices (RCPM)) was also used to measure cognitive ability in all children. This test was chosen since it is culturally-inclusive with norms for many countries and is suitable for the range of ages tested in this study.

Analysis

To explore visual development in typical children, continuous variables have been analyzed using IBM SPSS v. 28 and MS Excel for Mac v. 16. No significant differences in gender were revealed for any of the variables, thus all analyses were collapsed across gender. In individual analyses, any missing cases were excluded pairwise.

The Kolmogorov-Smirnoff (KS) test, and evaluations of histograms, probability-probability (P-P) plots and levels of skew and kurtosis were used for testing of normality.

R2-values for linear, exponential, and asymptotic fits were calculated, however, in all cases, the linear fit was either the best fit to the data or the other fits were not significantly better than the linear fit and so the linear fit has been used in all analyses.

Pearson correlations were calculated to look for associations between measures of visual function and age, cognitive ability, and visual acuity. Trajectories for change in visual function by age, cognitive ability and visual acuity were calculated where significant linear correlations were found. Partial correlations were used to determine which variable, age, visual acuity, or cognition, was the best predictor for the measures of visual function assessed.

Results

Results are presented in three stages: 1) correlations; 2) partial correlations for age, acuity and cognition; 3) developmental trajectories.

Correlations

First, Pearson's correlations were calculated to determine whether age, acuity and cognition were related to measures of visual function (Table 2). Each visual function, except for positive fusional vergence, accommodative amplitude and accommodative facility were found to correlate significantly with at least one of our explanatory variables: age, acuity, or cognition.

Partial Correlations

Since many of the scores on visual measures correlated significantly with more than one of our explanatory variables, we chose to use partial correlations to determine which variable(s) retained explanatory power when controlling for the other variables. For this analysis, we only analyzed the visual function variables that showed a significant correlation with age, acuity and/or cognition. The results of these analyses are described for each combination below.

Partial Correlations: Age Controlling for Cognitive Ability and Acuity

To investigate the moderating or mediating effect of cognitive ability and/or acuity on age, partial correlations between visual functions and age were calculated while controlling for cognition, acuity, or both (Table 3).

Table 2
Pearson correlations (r) between age, acuity, cognition, and scores on tests of vision with confidence intervals.

Measure	***r Age***	***95% CI***	***r Mean acuity***	**95% CI**	***r* Cognition**	**95% CI**	**df**
Outcome Variables							
Mean acuity	− .52***	− .66 to − .34					79
Cognition (RCPM)	.72***	.59 to .81	− .55***	− .68 to − .37			79
Acuity & Refraction							
Contrast sensitivity	− .18	− .39 to − .05	.58***	.40 to .71	− .26*	− .46 to − .03	79
Refraction	− .20	− .40 to .03	.34**	.13 to .52	− .19	− .39 to .03	79
Accommodation & Vergence							
NPC (Break-value)	.31**	.08 to .53	− .05	− .28 to .13	.18	− .04 to .40	83
PFV @ 40 cm	.08	− .15 to .31	− .14	− .32 to .07	.00	− .22 to .22	83
Vergence facility	.19	− .03 to .39	− .29**	− .50 to − .06	.19	− .07 to .41	83
Acc. amplitude	− .05	− .29 to .20	.01	− .18 to .22	− .01	− .22 to .21	83
Acc. facility	.12	− .09 to .33	− .04	− .24 to .16	.04	− .17 to .25	83
Higher Visual Functions							
DEM ratio	− .32**	− .54 to − .10	.33**	.12 to .52	− .39***	− .57 to − .20	83
GVT	.54***	.40 to .66	− .32**	− .50 to − .12	.50***	.36 to .64	83
Motion coherence	− .34***	− .52 to − .14	.27*	.07 to .45	− .56***	− .70 to − .40	83

CI = confidence intervals; df = degrees of freedom; RCPM = Raven's Colored Progressive Matrices; NPC = near point of convergence; PFV = positive fusional vergence;

Acc. = accommodation; DEM = developmental eye movements; GVT = Groffman visual tracing test

*Significant at the .05 level, **Significant at the .01 level, ***Significant at the .001 level (2-tailed)

Measure	*r Age*	*95% CI*	*r Mean acuity*	95% CI	*r* Cognition	95% CI	df
Form coherence	− .55***	− .66 to − .42	.41***	.17 to .58	− .64***	− .75 to − .51	83
CI = confidence intervals; df = degrees of freedom; RCPM = Raven's Colored Progressive Matrices; NPC = near point of convergence; PFV = positive fusional vergence;							
Acc. = accommodation; DEM = developmental eye movements; GVT = Groffman visual tracing test							
*Significant at the .05 level, **Significant at the .01 level, ***Significant at the .001 level (2-tailed)							

Table 3
Partial Pearson correlations (r) with confidence intervals for scores on vision tests that were significantly associated with age after controlling for acuity, cognition and both factors.

Measure	***r Age***	***r C. for acuity***	***95% CI***	***r C. for cognition***	***95% CI***	***r C. for both factors***	***95% CI***	***df***
Outcome Variables								
Mean acuity	− .52***			− .18	− .38 to .01			82
Cognition (RCPM)	.72***	.65***	.53 to .75					82
Accommodation & Vergence								
NPC (Break-value)	.31**	.34**	.09 to .56	.28**	.04 to .49	.29**	.05 to .52	80
Higher Visual Function								
DEM ratio	− .32**	− .20	− .45 to .01	− .08	− .35 to .21	− .04	− .33 to .20	77
GVT	.54***	.48***	.30 to .63	.33**	.15 to .50	.31**	.09 to .49	81
Motion coherence	− .34***	− .26*	− .48 to − .04	.07	− .15 to .28	.08	− .15 to .29	81
Form coherence	− .55***	− .47***	− .61 to − .33	− .22*	− .42 to .05	− .19	− .40 to .08	81

C. = controlling for; CI = confidence intervals; df = degrees of freedom; RCPM = Raven's Colored Progressive Matrices; NPC = near point of convergence;

PFV = positive fusional vergence; Acc. = accommodation; DEM = developmental eye movements; GVT = Groffman visual tracing test

*Significant at the .05 level, **Significant at the .01 level, ***Significant at the .001 level (2-tailed)

NPC remained significantly positively correlated with age after controlling for acuity, cognition, or both, with Age accounting for 12% of the variability in this function, $p < .001$ (Fig. 1a). Since NPC was positively correlated with age, children's ability to converge decreased (children could not converge to nearer targets) with age. The change in the steepness of the curve suggests that this occurs after 9 years of age.

Score on the Groffman Visual Tracing test (GVT) remained significantly positively correlated with age after controlling for both acuity and cognition. Score on the GVT increases with age indicating that

children’s ability to control their eye movements when tracing lines improves with age (Fig. 1b).

While changes NPC and GVT were found to be predicted by age, for all other visual measures, the variance explained by age is no longer significant when controlling for acuity and/or cognition. We therefore tested whether acuity or cognition are better predictors for these variables.

Partial Correlations: Acuity Controlling for Age and Cognitive Ability

The results for these partial correlations are displayed in Table 4.

Table 4

Partial Pearson correlations (r) with confidence intervals for scores on vision tests that were significantly associated with acuity after controlling for age, cognition and both factors.

Measure	***r Mean acuity***	**r C. for age**	***95% CI***	**r C. for cognition**	***95% CI***	**r C. for both factors**	***95% CI***	***df***
Outcome Variables								
Age	− .52***			− .18	− .38 to .01			
Cognition (RCPM)	− .55***	− .25*	− .43 to − .06					82
Acuity & Refraction Tests								
Contrast sensitivity	.58***	.64***	.49 to .76	.62***	.45 to .74	.63***	.45 to .75	74
Refraction	.34**	.25*	− .14 to .51	.26*	− .09 to .51	.24*	− .09 to .49	81
Accommodation & Vergence								
Vergence facility	− .29**	− .24*	− .45 to .00	− .23*	− .46 to .02	− .23*	− .44 to .02	81
Higher Visual Function								
DEM ratio	.33**	.26*	− .01 to .49	.23*	.00 to .43	.22	− .01 to .43	77
GVT	− .32**	− .12	− .33 to .09	− .13	− .35 to .08	− .08	− .29 to .12	81
Motion coherence	.27*	.16	− .07 to .38	.04	− .19 to .26	.05	− .18 to .27	81
Form coherence	.41***	.22*	.01 to .42	.17	− .05 to .37	.14	− .07 to .33	81

C. = controlling for; CI = confidence intervals; df = degrees of freedom; RCPM = Raven's Colored Progressive Matrices; NPC = near point of convergence;

PFV = positive fusional vergence; Acc. = accommodation; DEM = developmental eye movements; GVT = Groffman visual tracing test

*Significant at the .05 level, **Significant at the .01 level, ***Significant at the .001 level (2-tailed

The correlation between acuity and contrast sensitivity measured using the Bailey-Lovie 6 m low contrast acuity chart remained significant after controlling for age and cognition. As acuity increases, contrast sensitivity also increases (Fig. 2a).

Acuity remained significantly correlated with refraction after controlling for age and cognition.

Children with lower hyperopia had higher presenting visual acuity (Fig. 2b). Since the two most hyperopic children (SE > + 4.0 DS) might be driving this relationship, we re-analysed excluding these two children and found that the significant relationship between acuity and refraction remained.

Vergence facility was also significantly positively correlated with acuity when age and cognitive ability were controlled. Better visual acuity was associated with higher vergence facility (Fig. 2c). Four children were not able to perform this test (0 cycles/minute). Two of these children were diagnosed with strabismus. Removal of either these two, or all four children, from the analysis did not change the level of significance of the association. In all cases, the trajectory analysis suggests that vergence facility decreases below acuities of -0.2 logMAR.

While variance in contrast sensitivity, refraction and vergence facilitiy were significantly predicted by changes in acuity, the variance explained by acuity for all other variables no longer reached statistical significance when controlling for age, cognitive ability, or both.

Partial Correlations: Cognitive Ability Controlling for Age and Acuity

The results for partial correlations with cognition controlling for acuity, age and both are displayed in Table 5.

Cognitive ability remains significantly negatively associated with form and motion coherence after controlling for both age and acuity (Fig. 3a and b). In each case, higher cognition is associated with lower threshold or better performance on form and motion coherence tests.

Table 5

Partial Pearson correlations (r) with confidence intervals for scores on vision tests that were significantly associated with cognition after controlling for age, acuity and both factors.

Measure	***r* Cognition**	**r C. for acuity**	***95% CI***	**r C. for age**	***95% CI***	**r C. for both factors**	***95% CI***	***df***
Outcome Variables								
Age	.72***	.65***	.53 to .75					
Mean acuity	− .55***			− .25*	− .43 to − .06			82
Acuity & Refraction Tests								
Contrast sensitivity	− .26*	.02	− .24 to .25	− .18	− .40 to .04	− .06	− .33 to .18	74
Tests of Higher Visual Function						.05	− .20 to .25	81
DEM ratio	− .39***	− .27*	− .44 to − .08	− .24*	− .46 to .04	− .19	− .39 to .06	77
GVT	.50***	.41***	.23 to .58	.18	− .03 to .37	.15	− .06 to .35	81
Motion coherence	− .56***	− .49***	− .65 to − .30	− .45***	− .60 to − .28	− .43***	− .59 to − .26	81
Form coherence	− .64***	− .54***	− .69 to − .40	− .39***	− .60 to − .16	− .35***	− .56 to − .13	81

C. = controlling for; CI = confidence intervals; df = degrees of freedom; RCPM = Raven's Colored Progressive Matrices; NPC = near point of convergence;

PFV = positive fusional vergence; Acc. = accommodation; DEM = developmental eye movements; GVT = Groffman visual tracing test

*Significant at the .05 level, **Significant at the .01 level, ***Significant at the .001 level (2-tailed)

Discussion

The results presented here suggest that developmental changes in visual function cannot be explained by age alone: instead, visual acuity and cognitive ability independently account for significant variance in several higher visual functions.

Initial correlation analyses demonstrated that age, cognition, and acuity were all significantly associated with higher level visual functions. Partial correlations demonstrated that:

1. age was a significant predictor for near point of convergence and score on the Groffman Visual Tracing test after controlling for acuity and cognition.
2. Acuity was a significant predictor of contrast sensitivity, and refraction after controlling for cognition and age.
3. Cognition was a significant predictor of motion, and form, coherence after controlling for acuity and age.

Together, these findings suggest a that there are different drivers of visual development with lower-level functions more closely linked to acuity and higher-level perceptual tasks more dependent on cognitive ability.

Acuity and refraction tests.

Our test of contrast sensitivity (the Bailey-Lovie test) measures low contrast visual acuity, and it is therefore unsurprising that there is a significant positive correlation between contrast sensitivity – using this measure - and acuity. Neither is it surprising that the weaker significant relationship with cognition is lost when controlling for age or acuity. A different test of contrast sensitivity which measured a range of contrasts at selected spatial frequencies might produce a different result to that reported here.

Our data suggest that changes in refraction are better predicted by acuity than age. While a reduction in hypermetropia (measured using cycloplegic refraction) with age has been demonstrated in previous studies including much larger samples of typical children (e.g. Chiesi et al., 2009, Mantyjarvi, 1985), these studies did not consider developmental changes in acuity as an alternative explanation [18, 19].

The relationship between acuity and refraction observed here may reflect either the effect of refractive error on visual acuity, or conversely, the influence of acuity-driven visual experience on refractive development; two plausible mechanisms can be proposed: 1) children susceptible to myopia could be more detail-oriented or sensitive to blur and might therefore try harder to clear an image, increasing visual acuity; 2) it is also possible that it is the refractive condition itself (even after correction) that causes a reduction in acuity. For example, it is well known that high rates of hypermetropia are associated with a reduction in corrected visual acuity, especially for children who have not received their correction by the age of four years [20].

Accommodation and vergence tests.

The data for tests of accommodation and vergence resulted in an inconsistent profile with some improving, some remaining unchanged and some decreasing across development.

In our study, near point of convergence was found to decline (moves further from the eyes) with age, a finding which, though clinically surprising, has been described previously. [6], [21], [22] The increase found in vergence facility with age is also consistent with previous research. [2]

A possible explanation for increases in vergence facility alongside reduction in near point of convergence is that, while the ability to control vergence improves with age, the increase in interpupillary distance (IPD) with age leads to a greater demand for convergence at any given distance. Thus, a consistent convergent output will result in convergence further from the eyes as the IPD increases. Since IPD has been found to increase with age beyond puberty [23], age will be a significant negative predictor of NPC in school aged children even as vergence control improves.

Children's accommodation abilities can be assessed in several ways, only two of which are included here. The most common is to measure the accommodation amplitude, which is well known to decrease with age from approximately 8 to 70 years [25]. This reduction is not significant in the data reported from our study, probably due to limitations in the age-range tested, number of participants included, and a ceiling effect in the results. The mean binocular amplitude value of 16.1D +/-2.8D found in this study is, however, comparable to those found in other studies of school aged children [26–28].

Higher visual function tests.

Scores on the GVT test remained significantly positively correlated with age after controlling for our other variables which supports previous studies in Danish and American school children [31]. This is consistent with maturational improvements in eye movement control for our sample of children between five and eleven years old. Due to the floor effect; a large proportion of children below seven years of age scored zero points, however. The recommended starting point of seven years of age for this test should therefore be used.

Cognition is a better predictor then age and acuity for development of form and motion coherence tasks. Previous studies have used a range of different methods to measure form- and motion- coherence and this has led to differences in reported developmental trajectories. This is particularly the case for coherent motion abilities, which have been suggested to mature by the age of three years at the youngest [32], and in the teens at the latest [1, 33]. While studies suggesting reduced ability to detect coherent motion in a range of developmental disorders often have controlled for cognition [34–36], our results indicate that it will be important to have norms that control for cognition when testing motion and form coherence in typical children.

Limitations

Several limitations of this study should be considered when interpreting the findings. First, the cross-sectional design means that while age, acuity, and cognition can be identified as predictors of visual function at a given time point, no causal inferences can be drawn about the direction of these relationships. Longitudinal data would be needed to determine whether changes in acuity or cognitive ability drive subsequent changes in visual function, or whether the relationships are bidirectional.

Dry (non-cycloplegic) retinoscopy was used as the sole measure of refraction. While this decision was made to avoid the adverse effects of cycloplegia on children's subsequent test performance, it may have resulted in an underestimation of the true degree of hyperopia, particularly in younger children.

Floor and ceiling effects were observed for several tests. A large proportion of children below seven years of age scored zero on the Groffman Visual Tracing test, and children with strabismus obtained a score of zero on the vergence facility test. These effects limit the interpretability of developmental trajectories at the extremes of the age range and should be borne in mind when applying these findings to clinical practice.

Cognitive ability was assessed using a single measure, the Raven's Coloured Progressive Matrices, which primarily captures non-verbal reasoning and spatial ability. Other cognitive domains that may influence visual function, such as working memory, processing speed, or sustained attention, were not assessed, and this limits the ability to generalise findings across broader cognitive constructs.

Contrast sensitivity was measured monocularly in the worse eye, and at high spatial frequencies only. While this approach was methodologically justified, it does not reflect the peak binocular contrast sensitivity, which is more representative of everyday visual experience and may have produced different results.

Finally, all participants were recruited from two kindergartens and one school in Norway. Cultural, educational, and environmental factors specific to this sample may limit the generalisability of the normative trajectories reported here to children in other countries or educational contexts. Future studies employing longitudinal designs, broader cognitive batteries, larger and more diverse samples, and cycloplegic refraction would help to address these limitations and further clarify the relative contributions of age, acuity, and cognition to visual development across childhood.

Conclusions

In conclusion, visual development during the school years is not solely age dependent but is significantly influenced by both changes in visual acuity and cognitive ability. These findings challenge the reliance on age-based norms in clinical assessment and highlight the need for more individualized approaches. Future research should incorporate broader cognitive measures and longitudinal designs to further clarify these relationships.

Declarations

This research was conducted at Statped, dept. of Visual Impairment, Vitaminvn. 1a, 0485 Oslo, Norway

Consent to Publish Declaration: Both authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Arnulf Myklebust. The first draft of the manuscript was written by Arnulf Myklebust and both authors commented on previous versions of the manuscript. Both authors read and approved the final manuscript.

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Conflict of interest: The authors declare that they have no conflict of interest

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The authors declare they have no relevant financial or non-financial interests to disclose.

Ethics Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Ethics Committee of the University of Reading.

Preliminary results in the form of age-related trajectories for this group of children have been presented as a poster at the Child Vision Research Society Conference, Royal Visio, The Netherlands, in 2011.

References

1. Bogfjellmo, L.-G., P.J. Bex, and H.K. Falkenberg, *The development of global motion discrimination in school aged children.* J Vis, 2014. **14**(2): p. 1-12 http://dx.doi.org/10.1167/14.2.19.

2. Buzzelli, A.R., *Vergence facility: developmental trends in a school age population.* Am J Optom Physiol Opt, 1986. **63**(5): p. 351-5 http://dx.doi.org/10.1097/00006324-198605000-00005.
3. Facchin, A., S. Maffioletti, and T. Carnevali, *Validity reassessment of Developmental Eye Movement (DEM) test in the Italian population.* Optom Vis Dev, 2011. **42**(3): p. 155-167
4. Langaas, T., *Visual acuity in children: the development of crowded and single letter acuities.* Scand J Optom Vis Sci, 2011. **4**(2): p. 20-26 http://dx.doi.org/10.5384/SJOVS.vol4i2p20.
5. Leat, S.J., N.K. Yadav, and E.L. Irving, *Development of visual acuity and contrast sensitivity in children.* J Optom, 2009. **2**(1): p. 19-26 http://dx.doi.org/10.3921/joptom.2009.19.
6. Maagaard, M.L., I. Nisted, and T. Bek, *Independent development of refraction, accommodation and convergence over two years in primary school children.* Scand J Optom Vis Sci, 2015. **8**(1): p. 1-4 http://dx.doi.org/10.5384/SJOVS.vol8i1p1.
7. Myklebust, A., T. Langaas, and P.M. Riddell, *Developmental trajectories of selected visual functions*, in *Child Vision Resarch Society Conference*. 2011, Royal Visio: The Netherlands.
8. Walline, J.J., et al., *Development of phoria in children.* Optom Vis Sci, 1998. **75**(8): p. 605-10 http://dx.doi.org/10.1097/00006324-199808000-00026.
9. Atkinson, J. and O. Braddick, *Visual and visuocognitive development in children born very prematurely.* Prog Brain Res, 2007. **164**: p. 123-149 10.1016/S0079-6123(07)64007-2.
10. Burton, E., J. Wattam-Bell, and M. Nardini, *The impact of optical blur on cortical responses to global form and motion*, in *J Vis*. 2012. p. 754.
11. Myklebust, A.K. and P.M. Riddell, *Development of Visual Acuity in Children: Assessing the Contributions of Cognition and Age in LEA Chart Acuity Readings.* Optom Vis Sci, 2022. **99**(1): p. 24-30 10.1097/opx.0000000000001822.
12. Brown, B. and J.E. Lovie-Kitchin, *High and low contrast acuity and clinical contrast sensitivity tested in a normal population.* Optom Vis Sci, 1989. **66**(7): p. 467-73 10.1097/00006324-198907000-00010.
13. Garzia, R.P., et al., *A new visual-verbal saccade test: the development eye movement test (DEM).* J Am Optom Assoc, 1990. **61**(2): p. 124-35
14. Langaas, T., et al. *Clinical assessment of eye movements in children with reading disabilities and with developmental coordination disorder (DCD)*. Invest Ophthalmol Vis Sci, 2002. **43**.
15. Sperring, R., P. Riddell, and J. Stein, *The role of magnocellular visual processing in children with specific reading deficit: A random dot kinematogram study*, in *Child Vision Research Society Conference*. 2009: Cardiff University.
16. Stein, J. and V. Walsh, *To see but not to read; the magnocellular theory of dyslexia.* Trends Neurosci, 1997. **20**(4): p. 147-152 10.1016/s0166-2236(96)01005-3.
17. Stein, J.F., *Visual motion sensitivity and reading.* Neuropsychol, 2003. **41**(13): p. 1785-93 10.1016/s0028-3932(03)00179-9.
18. Chiesi, C., L. Chiesi, and G.M. Cavallini, *Evaluation of refraction in a statistically significant sample: changes according to age and strabismus.* J Pediatr Ophthalmol Strabismus, 2009. **46**(5): p. 266-72

http://dx.doi.org/10.3928/01913913-20090903-04.

19. Mantyjarvi, M.I., *Changes of refraction in schoolchildren.* Arch Ophthalmol, 1985. **103**(6): p. 790-2 http://dx.doi.org/10.1001/archopht.1985.01050060050022.
20. Friedburg, D. and K.P. Klöppel, *Frühzeitige Korrektion von Hyperopie und Astigmatismus bei Kindern führt zu besserer Entwicklung der Sehschärfe [Early correction of hyperopia and astigmatism in children leads to better development of visual acuity].* Klin Monatsbl Augenheilkd, 1996. **209**(07): p. 21-24 http://dx.doi.org/10.1055/s-2008-1035271.
21. Hayes, G.J., et al., *Normative values for the nearpoint of convergence of elementary schoolchildren.* Optom Vis Sci, 1998. **75**(7): p. 506-12 http://dx.doi.org/10.1097/00006324-199807000-00019.
22. Chen, A.H., D.J. O'Leary, and E.R. Howell, *Near visual function in young children. Part I: Near point of convergence. Part II: Amplitude of accommodation. Part III: Near heterophoria.* Ophthalmic Physiol Opt, 2000. **20**(3): p. 185-98 http://dx.doi.org/10.1016/S0275-5408(99)00056-3.
23. Pointer, J.S., *The far interpupillary distance. A gender-specific variation with advancing age.* Ophthalmic Physiol Opt, 1999. **19**(4): p. 317-326 http://dx.doi.org/10.1046/j.1475-1313.1999.00441.x.
24. McKee, S.P., *The spatial requirements for fine stereoacuity.* Vis Res, 1983. **23**(2): p. 191-198 http://dx.doi.org/10.1016/0042-6989(83)90142-6.
25. Duane, A., *Normal values of the accommodation at all ages.* J Am Med Assoc, 1912. **59**(12): p. 1010-1013 http://dx.doi.org/10.1001/jama.1912.04270090254042.
26. Eames, T.H., *Accommodation in school children, aged five, six, seven, and eight years.* Am J Ophthalmol, 1961. **51**: p. 1255-7
27. Koslowe, K., et al., *Accommodative amplitude determination: Pull-away versus push-up method.* Optom Vis Dev, 2010. **41**(1): p. 28-32
28. Sterner, B., M. Gellerstedt, and A. Sjostrom, *The amplitude of accommodation in 6-10-year-old children - not as good as expected!* Ophthalmic Physiol Opt, 2004. **24**(3): p. 246-51 http://dx.doi.org/10.1111/j.1475-1313.2004.00201.x.
29. Fernandez-Velazquez, F.J. and M.J. Fernandez-Fidalgo, *Do DEM test scores change with respect to the language? Norms for Spanish-speaking population.* Optom Vis Sci, 1995. **72**(12): p. 902-6 http://dx.doi.org/10.1097/00006324-199512000-00009.
30. Pang, P.C., C.S. Lam, and G.C. Woo, *The developmental eye movement (DEM) test and Cantonese-speaking children in Hong Kong SAR, China.* Clin Exp Optom, 2010. **93**(4): p. 213-23 http://dx.doi.org/10.1111/j.1444-0938.2010.00470.x.
31. Falcke, D., K. Kristiansen, and P. Harris, *Comparison of Danish and American children on the Groffman Visual Tracing test.* Optom Vis Dev, 1998. **29**(2): p. 78-82
32. Parrish, E.E., et al., *The maturation of form and motion perception in school age children.* Vision Res, 2005. **45**(7): p. 827-37 http://dx.doi.org/10.1016/j.visres.2004.10.005.

33. Hadad, B.S., D. Maurer, and T.L. Lewis, *Long trajectory for the development of sensitivity to global and biological motion.* Dev Sci, 2011. **14**(6): p. 1330-9 http://dx.doi.org/10.1111/j.1467-7687.2011.01078.x.
34. Atkinson, J., et al., *A specific deficit of dorsal stream function in Williams' syndrome.* Neuroreport, 1997. **8**(8): p. 1919-22 http://dx.doi.org/10.1097/00001756-199705260-00025.
35. Cornelissen, P., et al., *Contrast sensitivity and coherent motion detection measured at photopic luminance levels in dyslexics and controls.* Vis Res, 1995. **35**(10): p. 1483-1494 http://dx.doi.org/10.1016/0042-6989(95)98728-R.
36. Milne, E., et al., *High motion coherence thresholds in children with autism.* J Child Psychol Psychiatry, 2002. **43**(2): p. 255-263 http://dx.doi.org/10.1111/1469-7610.00018.
37. Schmidtke, A. and S. Schaller, *Comparative study of factor structure of Raven's Coloured Progressive Matrices.* Percept Mot Skills, 1980. **51**(3 Pt 2): p. 1244-6 http://dx.doi.org/10.2466/pms.1980.51.3f.1244.

Figures

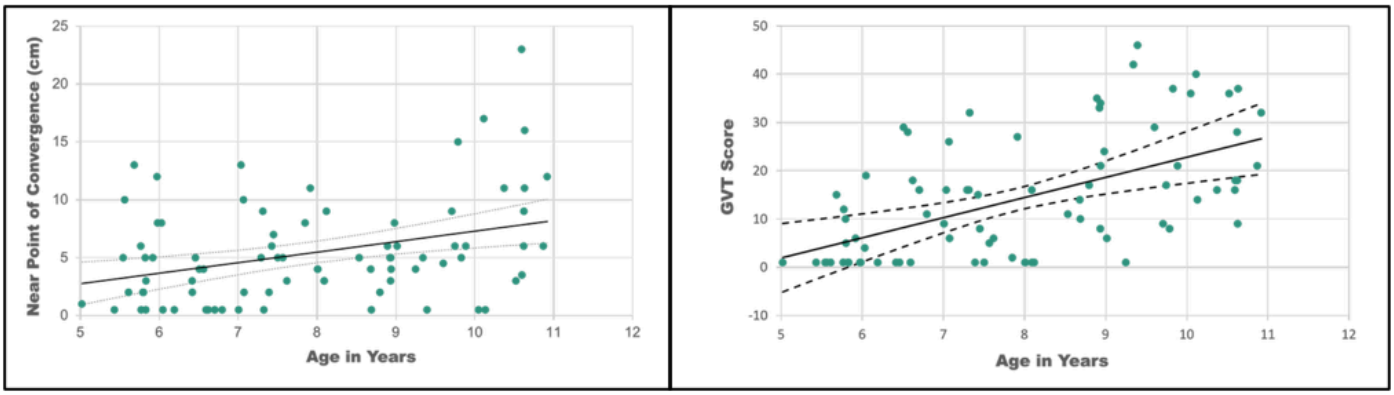


Figure 1a

Figure 1b

Figure 1

Scatterplots showing statistically significant relationship between age and visual measures.

Fig. 1a (left) scatterplot for the near point of convergence (NPC) and age. R = .29, *P* < .001. This suggests that near point of convergence recedes with increasing age.

Fig. 1b (right) Scatterplot showing relationship between score on the Groffman visual tracing test (GVT) and age. R = .31, *P* < .001. This suggests that line-tracing abilities improve with increasing age across the whole age range tested

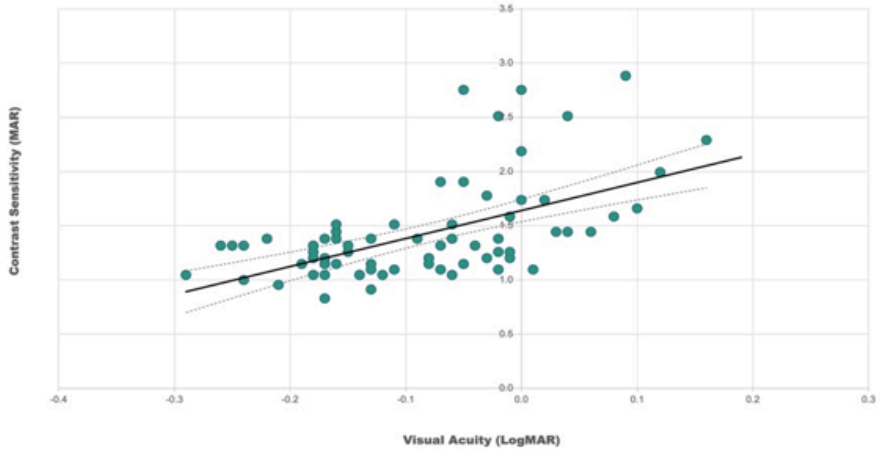


Figure 2a

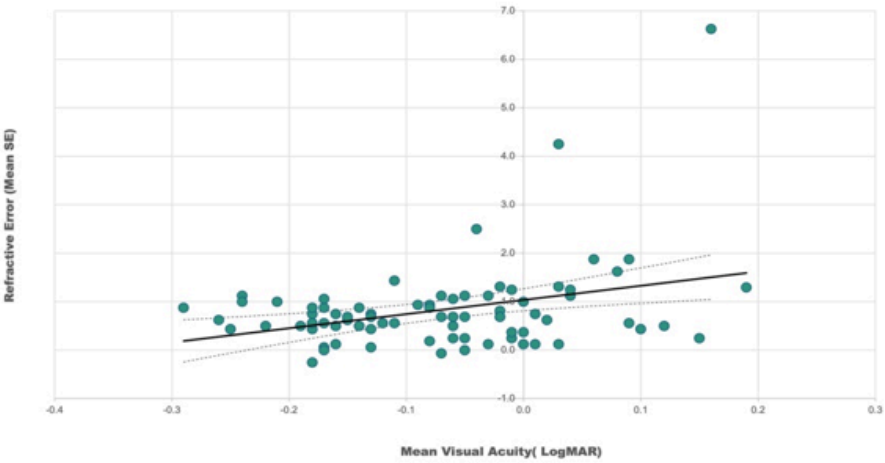


Figure 2b

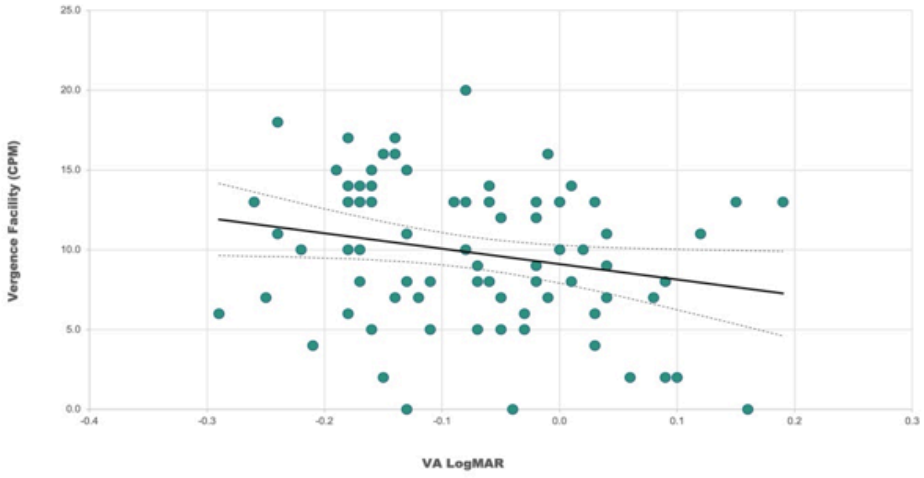


Figure 2c

Figure 2

a-c Scatterplots showing relationship between:

a) contrast sensitivity and acuity; R = .63, *P* < .001. The data suggest improvements in Bailey Lovie contrast sensitivity as a function of visual acuity

b) refraction (Mean Spherical Equivalent while wearing habitual correction) and acuity. R = .35, *P* < .001. This suggests that acuity decreases as hyperopia increases. Two children measured above +4.0DS (SE) and when these children are excluded, R decreases to 0.24, *P* < .05 (1-tailed)

c) between vergence facility and acuity. R = -.23, *P* < .05. This suggests that the ability to make rapid changes in vergence decreases with decreasing acuity

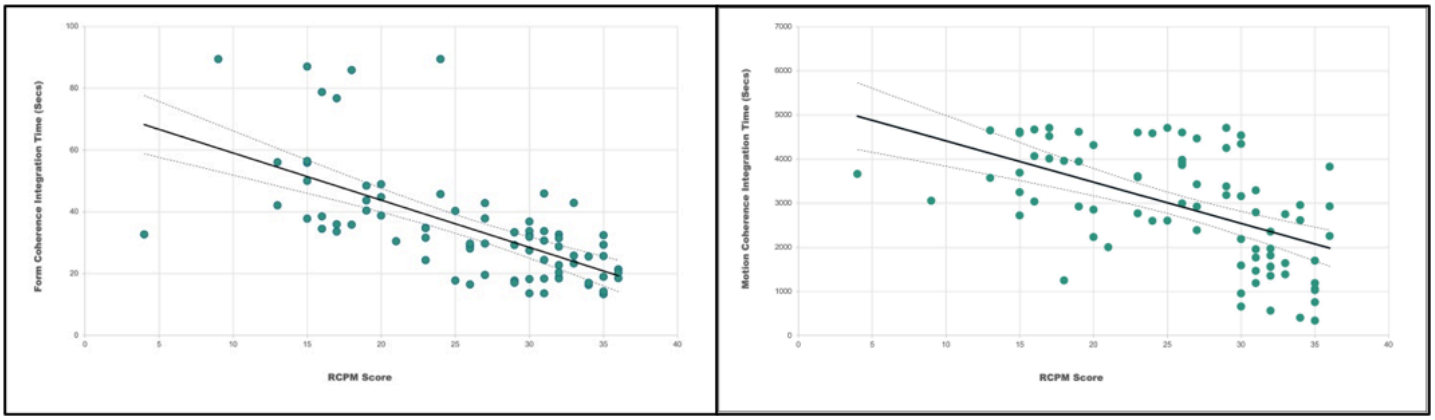


Figure 3a

Figure 3b

Figure 3

Scatterplot showing relationship between

a) form coherence threshold and cognition; R = -.43, *P* < .001. The data are best fit with a straight line. This suggests that ability to detect coherent form (lower threshold) increases as cognition increases

b) Scatterplot showing relationship between motion coherence threshold and cognition; R = -.35, *P* < .001. The data are best fit with a straight line. This suggests that ability to integrate coherent motion over time (lower threshold) improves with increases in cognition