Independence between age-related changes in refraction, accommodation and convergence in primary school children

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Received August 21, 2013, accepted November 22, 2013
Keywords: Development, refraction, accommodation, convergence, children
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Abstract
The parameters which describe how refraction, accommodation and convergence develop during childhood are well understood, but the possible interdependencies between these age-related changes are not known. Hence it is unknown whether refractive development is associated with development of accommodation and convergence. Four-hundred and fifty-two unselected 7-13 year old school children were subjected to autorefraction and unilateral cover test, and measurement of visual acuity, amplitude of accommodation, monocular accommodation facility, near phoria, near point of convergence, and positive and negative fusional vergence using subjective techniques. Linear regression was used to study the correlation of these parameters with age, followed by study of correlations between age-dependent parameters. There was a significant reduction in hyperopia (0.13 D/year, 95% CI [−0.20, −0.06]), a significant increase in the monocular accommodation facility (0.48 cpm/year, 95% CI [0.18, 0.79]), and a non-significant shift towards convergence of the midpoint of the fusional range (0.43 $^{\triangle}$D/year, 95% CI [0.12, 0.74]) with age. Age-dependent variables were not significantly correlated. Autorefraction was not correlated with any other variable. None of the other parameters showed any significant correlations with age. Age-related changes in refraction, monocular accommodation facility and midpoint of fusional range were independent. This indicates that the development of these parameters involves separate processes, and suggests that therapeutic intervention may be performed on these parameters individually without a derived effect on the other age-related parameters.

Sammendrag
Mens det er velkendt, at refraktion og konvergens- og akkommodationsparametre udvikler sig i barndommen, er den mulige interne afhængighed i udviklingen af disse parametre ikke velundersøgt. Det er derfor uklart, om udvikling i refraktion er associeret med udvikling i akkommodation og konvergens. 452 uselekterede 7-13-årige skolebørn fik målt visus, unilateral covertest, autorefraktion, akkommodationsamplitude, monokulær akkommodationsfacilitet, nærfori, konvergensnærpunkt samt positiv og negativ fusionsvergens. Lineær regression blev først anvendt til at undersøge korrelationen mellem disse parametre og alder, og efterfølgende til at undersøge korrelationen mellem de aldersafhængige parametre. Der var signifikant reduktion i hyperopi (−0.13 D/år, 95% CI [−0.20, −0.06]), signifikant forøgelse i monokulær akkommodationsfacilitet (0.48 cpm/år, 95% CI [0.18, 0.79]) og tendens til et mere konvergent midtpunkt af fusionsbredden (0.43 $^{\triangle}$D/år, 95% CI [0.12, 0.74]) med alderen. Ingen af de aldersafhængige variable var signifikant internt korrelerede. Autorefraktion var ikke signifikant korreleret med nogen af de øvrige variable. Aldersafhængige forandringer i refraktion, monokulær akkommodationsfacilitet og midtpunkt af fusionsbredden var uafhængige af hinanden. Dette indikerer, at udviklingen af disse parametre er separate processer, hvilket peger på, at behandling kan udføres på en af disse parametre uden at have en afledt effekt på de øvrige aldersrelaterede parametre.

Introduction
The average refraction of children at birth is in the hyperopic range and gradually declines during childhood as the eye grows and its axial length increases (Goldschmidt, 1969; Larsen, 1971). The presence of hyperopia implies a need for accommodation in order to obtain clear vision at long distance, and to accommodate even further when the child needs to focus near objects. Accommodation is linked to miosis and convergence (Kaufman & Alm, 2003), but when the need for accommodation is excessive, as in hyperopia, the balance between accommodation, miosis and convergence may be disturbed, resulting in strabismus. This accommodative strabismus may include both latent forms such as convergence insufficiency (Daum, 1984), convergence excess (Gallaway & Scheiman, 1997) and accommodative insufficiency (Daum, 1983), or manifest strabismus with accompanying amblyopia (Webber, 2011).

In recent years, several studies have shown that the amplitude of accommodation decreases (Jimenez, Gonzalez, Perez, & Garcia, 2003), monocular accommodative facility increases (Scheiman, Herzberg, Frantz, & Margolies, 1988), near phoria becomes more convergent (Walline, Mutti, Zadnik, & Jones, 1998), near point of convergence recedes (Chen, O'Leary, & Howell, 2000), and fusional vergence decreases (Lyon, Goss, Horner, Downey, & Rainey, 2005) with age during early childhood, simultaneously with the change in refraction (Bharadwaj & Candy, 2008). However, previous studies have been carried out on selected patient groups, and a possible interdependence between the parameters which correlate with age, has not been studied in detail.

The aim of the present study was to examine whether the age-related changes in refraction co-vary with changes in parameters describing accommodation and convergence in an unselected group of Danish school children.

Methods

Design
The study was designed as a prospective cohort study of refraction and binocular vision among representative Danish school children from 2nd, 4th and 6th grade. This paper reports baseline data from the study.

Subjects
Between 2006 and 2009 children in 2nd, 4th and 6th grade at four primary schools in the municipality of Randers, Denmark were invited to take part in the study. Since the present study reports baseline data, only the first data set from each child was included in the analysis (Table 1).

According to public records (Danish Ministry for Economic Affairs and the Interior, 2012) the study population did not differ from the Danish population with respect to educational level and occupational status of the parents, proportion of citizens from non-Western countries, proportion of single parents, public expenses to schools per citizen and class size. Altogether 508 children (271 boys and 237 girls) were invited to participate by a letter to their parents describing the purpose of the study. All accepted. Forty-two children were absent on the day of examination and could therefore not be included. The distribution of age and sex was similar among participants and non-participants.

Table 1: The number and mean age (SD) of children examined from each grade.

	Grade		
	2nd	4th	6th
n	187	203	76
Age	8.1(0.4)	10.1(0.4)	12.1(0.4)

Note. Age in years, M(SD)

Eight children with manifest esotropia and six with manifest exotropia were excluded in order to avoid sensory adaptation to strabismus invalidating measures of fusional vergence. The age of the remaining 452 children (89.0%) ranged between 7 and 13 years (mean = 9.5 years). It was calculated that with a minimum of $n = 408$ observations the detection of a change in refraction of 0.07 D/year, in monocular accommodation facility of 0.2 cpm/year and in midpoint of fusional range of 0.4 $^{\triangle}$D/year could be obtained with a power of 90% at a significance level of 5%.

Examination

All examinations were performed during school hours between 8.00 am and noon. Two classrooms were equipped for the examination with separate stations for each of the measures. The children were guided between the stations in random order to avoid systematic carry-over effects from one test to the next. The examination of an entire class took approximately 45 minutes. Experienced final year optometry students from the Danish College of Optometry and Visual Science (DCOVS) carried out the examinations. In order to minimise inter-individual variation, each examiner only carried out one specific test. All procedures followed standard protocol (Benjamin, 2006; Elliott, 2007). For each child the age, sex and grade were noted.

Each examination consisted of the following steps:

a) Visual acuity with habitual correction

Visual acuity was measured monocularly at 4 m distance with a retro illuminated logMAR chart (Precision Vision chart Illuminator, cat. no 2305), with five tumbling E optotypes on each line. An eye patch was used to cover the non-examined eye. When a child reported having glasses but was not wearing them, unaided visual acuity was recorded.

b) Refraction

- The refraction of habitually worn glasses was measured using a lensmeter (Nikon OL-7)
- Objective non-cycloplegic refraction was determined for each eye with a Topcon RM-A7000 autorefractor and the average of the mean sphere of three recordings was recorded

c) Orthoptic examination.

All examinations were performed with habitual correction, and consisted of:

- Unilateral cover test at 6 m to detect intermittent and manifest strabismus while the child viewed a vertical line of 6/9 (Snellen fraction) letters
- Measurement of horizontal dissociated phoria with the modified Thorington method as described by Rainey, Schroeder, Goss, and Grosvenor (1998), i.e. the child viewed a light source positioned centrally on a horizontal line of letters at a distance of 40 cm while reporting the position of a vertical line generated by a Maddox rod placed before the right eye
- Near point of convergence was measured in centimetres with a RAF ruler and a non-accommodative target (a vertical line) which was moved slowly towards the child. The break point was recorded when the child reported diplopia or if loss of fixation was observed
- Monocular amplitude of accommodation for each eye was measured in dioptres by use of push-up technique with a RAF ruler with a horizontal line of 0.4/0.6 (Snellen fraction) letters. The position for first sustained blur was recorded
- Negative fusional vergence and positive fusional vergence were measured at 40 cm with a prism bar with the subject viewing a vertical line of 0.4/0.6 (Snellen fraction) letters. Break was recorded when the child reported diplopia or when an eye movement opposite to the expected direction was observed
- Monocular accommodation facility was measured with accommodative flippers ($\pm$2.00 D) while the child viewed a horizontal line of 0.4/0.6 (Snellen fraction) letters for a period of one minute. The child reported when the line was seen clearly and the number of cycles was recorded (cpm). An eye patch was used to cover the non-examined eye

The study adhered to the tenets of the Declaration of Helsinki and was approved by the Danish Data Protection Agency and by The Regional Scientific Ethics Committee.

Data analysis

The total fusional range was derived by adding numerical values of positive fusional vergence and negative fusional vergence and the midpoint of fusional range was calculated in order to examine possible changes in amplitude and direction with age.

All data from the case sheets were entered twice into Microsoft Excel (version 2007) and were subsequently imported into Stata SE version 11 for validation and statistical analysis.

Statistical methods

One-way ANOVA showed no significant differences in covariates between boys and girls, and therefore data were not stratified by sex. Developmental trends were examined by simple linear regression comparing all variables with age. Subsequently simple linear regression was used to compare all variables mutually.

Spearman's rank correlation had no effect on conclusions for non-normal data; hence only linear regression coefficients were reported. All analyses of refraction were repeated using spherical equivalent, which did not alter results. For all analyses only results from right eye were reported since use of data from left eye or the average from the two eyes did not affect the conclusions. The analyses were followed by Bonferroni correction of p-values to adjust for multiple comparisons.

Results

The regression analyses of the studied parameters with age are shown in Table 2. It appears that there was a significant reduction in hyperopia, a significant increase in the monocular accommodation facility, and a tendency to a shift of the midpoint of the fusional range towards convergence with age, whereas distance visual acuity, near point of convergence, amplitude of accommodation, near phoria and fusional range at 40 cm showed no significant change with age.

The results of the mutual comparisons of age-dependent variables with all other variables are shown in Table 3. It appears that refraction was not correlated with any of the other parameters studied, and none of the age-dependent parameters were significantly correlated with each other. However, a larger monocular accommodation facility was significantly correlated with larger amplitude of accommodation. Additionally, a more convergent midpoint of the fusional range correlated with increased fusional range, larger amplitude of accommodation,

Table 2: Results from linear regression of the variables as a function of age expressed as regression coefficient with 95% CI and p-values.

Variable	Regression coefficient	95% CI	p
Distance visual acuity (logMAR) †	−0.02	−0.10, 0.06	1.00
Autorefraction Sphere (D) ‡	−0.13	−0.20, −0.06	0.001
Monocular amplitude of accommodation (D) §	−0.02	−0.27, 0.22	1.00
Monocular accommodation facility (cpm)[a]	0.48	0.18, 0.79	0.02
Near phoria (△D) †	0.05	−0.17, 0.27	1.00
Near point of convergence (cm) §	−0.08	−0.36, 0.20	1.00
Fusional range (△D) §	−0.15	−0.97, 0.66	1.00
Midpoint of fusional range (△D) §	0.43	0.12, 0.74	0.06

† n = 444; ‡ n = 446; § n = 445; ¶ n = 438

Table 3: Results from linear regression for mutual comparison of age-related variables with all other variables (regression coefficient, 95% CI, p-value).

	Distance visual acuity (logMAR)	Monocular amplitude of accommodation (D)	Near phoria (△D)	Near-point of convergence (cm)	Fusional range (△D)	Midpoint of fusional range (△D)	Monocular accommodation facility (cpm)
Autorefraction, Sph (D)	-0.03 [-0.04, -0.01] p < 0.001†	-0.04 [-0.37, 0.29] p = 1.00	0.10 [-0.20, 0.39] p = 1.00	0.37 [-0.04, 0.80] p = 1.00	-0.58 [-1.70, 0.55] p = 1.00	-0.33 [-0.76, 0.10] p = 1.00	0.21 [-0.21, 0.64] p = 1.00
Monocular accommodation facility (cpm)	0.00 [-0.01, -0.00] p = 0.54	0.12 [0.05, 0.19] p = 0.02	0.02 [-0.05, 0.08] p = 1.00	0.01 [-0.08, 0.10] p = 1.00	0.34 [0.09, 0.59] p = 0.14	0.07 [-0.02, 0.17] p = 1.00	
Midpoint of fusional range (ΔD)	-0.00 [-0.00, 0.00] p = 1.00	0.15 [0.08, 0.22] p < 0.001	0.14 [0.07, 0.20] p < 0.001	-0.11 [-0.20, 0.02] p = 0.18	1.63 [1.44, 1.83] p < 0.001		

† Association not significant when adjusted for uncorrected ametropia (p = 0.90).

and a shift towards increased convergence in near phoria (towards higher esophoria or lower exophoria), but not with the near point of convergence.

Discussion

The present study has shown a significant reduction in hyperopia, a significant increase in monocular accommodation facility and a tendency to a shift towards a more convergent midpoint of the fusional range with age among school children between 7 and 13 years of age, but these changes were mutually independent. All measurements were performed in free space in order to optimize reproducibility (Casillas & Rosenfield, 2006) and the fact that left eye measurements correlated with those of right eyes is an indication that the measurements were reproducible.

Most previous studies of refraction, accommodation and convergence in children were less likely to be representative for school children in general because of inclusion of selected patient groups possibly leading to an overrepresentation of children with abnormal accommodation and convergence (Abdi & Rydberg, 2005), or because of lack of consideration of demographic and socio-economic factors influencing the studied variables (Jimenez et al., 2003). Therefore, in order to elucidate the true association between refraction and parameters describing accommodation and convergence in the population, the present study was performed on a representative sample of Danish school children.

It has previously been shown that the studied parameters can be measured reliably in children between 7 and 13 years of age (Scheiman et al., 1988; Lyon et al., 2005). Previous studies of the validity of non-cycloplegic autorefraction show that hyperopia in excess of 2 D is underestimated (Williams, Miller, Northstone, & Sparrow, 2008); however in the present study this group consisted of only fourteen children and the exclusion of these individuals from the analysis had no effect on the conclusions (data not shown).

The reduction in hyperopia with age found in the study is in accordance with findings from other studies (Pointer, 2001) and can be attributed to an increase in axial length of the eye (Larsen, 1971), partly due to the normal growth of the eye and partly to the increased time spent on near visual tasks with increasing age (Jacobsen, Jensen, & Goldschmidt, 2008). Similarly, the increase in monocular accommodation facility with age is consistent with previous studies (Hennessey, Iosue, & Rouse, 1984; Jimenez et al., 2003; Scheiman et al., 1988) and is probably due to maturation of the oculomotor system since a high facility is dependent on the ability to both increase and decrease accommodation rapidly (Kaufman & Alm, 2003). The tendency towards a shift of the midpoint of the fusional range towards convergence differs from a previous study that found only reduced fusional range with age (Jimenez, Perez, Garcia, & Gonzalez, 2004). However, these findings relied on the subjective response of the children only, which may result in higher values of positive and negative fusional vergence in the youngest children leading to an overestimation of the fusional range in this age group. The examinations performed in the present study included objective measurements, and the shift of the midpoint of the fusional range towards convergence corroborates several other studies (Lyon et al., 2005). The findings might be due to cognitive maturation that increases the ability to maintain fixation on a selected object for a longer period of time during convergence than during divergence, since the latter is more limited by anatomical restrictions. However, the finding might also be due to the increased time spent on near visual tasks that necessitates a simultaneous convergence movement. The lack of dependence of the amplitude of accommodation, the near point of convergence and the convergent shift in near phoria with age also differs from other studies, probably because of the relatively low age of the children included in the present study (Walline et al., 1998) or because such differences were too small to be detected with the available data (Jensen, 1991).

In order to elucidate how the visual system matures during childhood it is pertinent to assess how the age-dependent variables co-vary with other orthoptic variables. The lack of correlation of refraction with the other studied parameters is contrary to previous studies, which found a correlation between moderate hyperopia and both latent strabismus (Leone et al., 2010) and the amplitude of accommodation (Fledelius, 1981). However, this discrepancy may be due to a lower prevalence of hyperopia and higher amplitude of accommodation due to lower age of

doi:10.5384/SJOVS.vol6i2p6 - ISSN: 1891-0890

the children included in the present study. Furthermore, experimental findings of accommodation and vergence gain suggest no correlation with refraction (Bharadwaj & Candy, 2008).

The positive correlation between monocular accommodation facility and amplitude of accommodation may be a consequence of the maturation of the visual system with an increasing ability to maintain focus during the examination procedures or that the lower amplitude of accommodation limits the ability to increase accommodation during the monocular accommodation facility test (Yothers, Wick, & Morse, 2002). This suggests that intervention on either of these parameters may affect the other and may therefore have implications for therapeutic strategies for disturbances in accommodation (Cooper et al., 1987).

In conclusion, the study has confirmed previous findings of an age-dependent reduction in hyperopia, an increase in monocular accommodation facility and a convergent shift of the fusional range among school children. However, the study also showed that the age-related changes in these parameters were independent. This finding suggests the presence of separate mechanisms regulating the development of these parameters, but also suggests that therapeutic intervention can be performed on these variables individually without a derived effect on other age-related parameters. However, prospective observational studies are needed in order to fully elucidate whether the observed age-related changes in refraction and orthoptic parameters are independent over time.

Acknowledgements

The study was supported by Synoptik-Fonden and The VELUX Foundation.

References

Abdi, S., & Rydberg, A. (2005). Asthenopia in schoolchildren, orthoptic and ophthalmological findings and treatment. *Documenta Ophthalmologica*, *111*(2), 65-72. doi:10.1007/s10633-005-4722-4

Benjamin, W. J. (2006). *Borish's clinical refraction* (Second ed.). Butterworth-Heinemann.

Bharadwaj, S. R., & Candy, T. R. (2008). Cues for the control of ocular accommodation and vergence during postnatal human development. *Journal of Vision*, *8*(16). doi:10.1167/8.16.14

Casillas, E. C., & Rosenfield, M. (2006). Comparison of subjective heterophoria testing with a phoropter and trial frame. *Optometry & Vision Science*, *83*(4), 237-241. doi:10.1097/01.opx.0000214316.50270.24

Chen, A., O'Leary, D., & Howell, E. (2000). Near visual function in young children. Part I: Near point of convergence. Part II: Amplitude of accommodation. Part III: Near heterophoria. *Ophthalmic and Physiological Optics*, *20*(3), 185-198. doi:10.1016/S0275-5408(99)00056-3

Cooper, J., Feldman, J., Selenow, A., Fair, R., Buccerio, F., MacDonald, D., & Levy, M. (1987). Reduction of asthenopia after accommodative facility training. *American Journal of Optometry and Physiological Optics*, *64*(6), 430-436. doi:10.1097/00006324-198706000-00008

Danish Ministry for Economic Affairs and the Interior. (2012). *De kommunale nøgletal*. http://www.noegletal.dk/. (Retrieved 10:12:12)

Daum, K. (1983). Accommodative insufficiency. *American Journal of Optometry and Physiological Optics*, *60*(5), 352-359. doi:10.1097/00006324-198305000-00002

Daum, K. (1984). Convergence insufficiency. *American Journal of Optometry and Physiological Optics*, *61*(1), 16-22. doi:10.1097/00006324-198401000-00003

Elliott, D. B. (2007). *Clinical procedures in primary eye care* (Third ed.). Butterworth Heineman Elsevier.

Fledelius, H. (1981). Accommodation and juvenile myopia. *Documenta Ophthalmologica Proceedings Series*, *28*, 103-108. doi:10.1007/978-94-009-8662-6_15

Gallaway, M., & Scheiman, M. (1997). The efficacy of vision therapy for convergence excess. *Journal of the American Optometric Association*, *68*(2), 81-86.

Goldschmidt, E. (1969). Refraction in the newborn. *Acta Ophthalmologica*, *47*(3), 570-578. doi:10.1111/j.1755-3768.1969.tb08143.x

Hennessey, D., Iosue, R., & Rouse, M. (1984). Relation of symptoms to accommodative infacility of school-aged children. *American Journal of Optometry and Physiological Optics*, *61*(3), 177. doi:10.1097/00006324-198403000-00005

Jacobsen, N., Jensen, H., & Goldschmidt, E. (2008). Does the level of physical activity in university students influence development and progression of myopia? A 2-year prospective cohort study. *Investigative Ophthalmology & Visual Science*, *49*(4), 1322-1327. doi:10.1167/iovs.07-1144

Jensen, H. (1991). Myopia progression in young school children. A prospective study of myopia progression and the effect of a trial with bifocal lenses and beta blocker eye drops. *Acta ophthalmologica. Supplement*(200), 1-79.

Jimenez, R., Gonzalez, M., Perez, M., & Garcia, J. (2003). Evolution of accommodative function and development of ocular movements in children. *Ophthalmic and Physiological Optics*, *23*(2), 97-107. doi:10.1046/j.1475-1313.2003.00093.x

Jimenez, R., Perez, M., Garcia, J., & Gonzalez, M. (2004). Statistical normal values of visual parameters that characterize binocular function in children. *Ophthalmic and Physiological Optics*, *24*(6), 528-542. doi:10.1111/j.1475-1313.2004.00234.x

Kaufman, P. L., & Alm, A. (2003). *Adler's physiology of the eye, clinical application* (Tenth ed.). Mosby.

Larsen, J. (1971). The sagittal growth of the eye. *Acta Ophthalmologica*, *49*(2), 239-262. doi:10.1111/j.1755-3768.1971.tb00949.x

Leone, J., Cornell, E., Morgan, I., Mitchell, P., Kifley, A., Wang, J., & Rose, K. (2010). Prevalence of heterophoria and associations with refractive error, heterotropia and ethnicity in Australian school children. *British Journal of Ophthalmology*, *94*(5), 542-546. doi:10.1136/bjo.2009.163709

Lyon, D., Goss, D., Horner, D., Downey, J., & Rainey, B. (2005). Normative data for modified Thorington phorias and prism bar vergences from the Benton-IU study. *Optometry-Journal of the American Optometric Association*, *76*(10), 593-599.

Pointer, J. (2001). A 6-year longitudinal optometric study of the refractive trend in school-aged children. *Ophthalmic and Physiological Optics*, *21*(5), 361-367. doi:10.1016/S0275-5408(01)00012-6

Rainey, B. B., Schroeder, T. L., Goss, D. A., & Grosvenor, T. P. (1998). Interexaminer repeatability of heterophoria tests. *Optometry & Vision Science*, *75*(10), 719-726. doi:10.1097/00006324-199810000-00016

Scheiman, M., Herzberg, H., Frantz, K., & Margolies, M. (1988). Normative study of accommodative facility in elementary schoolchildren. *American Journal of Optometry and Physiological Optics*, *65*(2), 127-134. doi:10.1097/00006324-198802000-00009

Walline, J., Mutti, D., Zadnik, K., & Jones, L. (1998). Development of phoria in children. *Optometry & Vision Science*, *75*(8), 605-610. doi:10.1097/00006324-199808000-00026

Webber, A. (2011). Paediatric hyperopia, accommodative esotropia and refractive amblyopia. *Clinical and Experimental Optometry*, *94*(1), 108-111. doi:10.1111/j.1444-0938.2010.00537.x

Williams, C., Miller, L., Northstone, K., & Sparrow, J. (2008). The use of non-cycloplegic autorefraction data in general studies of children's development. *British Journal of Ophthalmology*, *92*(5), 723-724. doi:10.1136/bjo.2007.136051

Yothers, T., Wick, B., & Morse, S. (2002). Clinical testing of accommodative facility: Part II. Development of an amplitude-scaled test. *Optometry*, *73*(2), 91-102.