Independent development of refraction, accommodation and convergence over two years in primary school children

Marianne L. Maagaard[1], Ivan Nisted[1] and Toke Bek[2]

[1]Danish College of Optometry and Visual Science, 8960 Randers SØ, Denmark.
[2]Department of Ophthalmology, Aarhus University Hospital, 8000 Aarhus C, Denmark.

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Correspondence: mlm@dcovs.dk

Abstract
Purpose: To examine whether age-related changes in refraction covary with changes in parameters describing accommodation and convergence over time in a group of Danish school children.

Methods: Two-hundred and seventy-eight unselected Danish school children (7.1–13.9 years) without manifest strabismus were studied at baseline and after two years. Each examination included measurement of distance visual acuity, unilateral cover test, non-cycloplegic autorefraction, monocular amplitude of accommodation, monocular accommodation facility, near phoria, near point of convergence, and positive and negative fusional vergence. The changes in the measured parameters were studied over time, followed by the testing for dependences in the development of these parameters.

Results: After two years there was a significant improvement in distance visual acuity ($p = 0.04$) and monocular accommodation facility ($p < 0.001$), an increased near point exophoria ($p = 0.04$) and fusional range ($p < 0.001$), a significant reduction in hyperopia ($p = 0.01$) and monocular amplitude of accommodation ($p < 0.001$), a receding near point of convergence ($p = 0.01$), while the midpoint of the fusional range changed significantly towards convergence ($p < 0.001$). The decline in near point of convergence correlated significantly with the decrease in monocular amplitude of accommodation ($p < 0.001$) and the convergent shift in the midpoint of the fusional range was significantly correlated with a larger fusional range ($p < 0.001$). The changes in all other parameters were independent.

Conclusions: The development of refraction, accommodation, and convergence parameters in school children over a two year period are independent. This may be due to separate processes regulating development, and suggests that therapeutic intervention may be performed on each of the parameters individually without a derived effect on the other parameters.

Sammendrag
Formål: At studere om aldersbetingede ændringer i øjets refraktion hos danske skolebørn har en sammenhæng med aldersbetingende ændringer i konvergens- og akkommodation over tid.

Fremgangsmåde: 278 repræsentative 7.1–13.9 årige danske skolebørn uden manifest skelen blev undersøgt ved baseline og ved opfølgning efter to år. Hver undersøgelse inkluderede måling af afstandsvisus, non-cykloplegisk autorefraktion, monokulær akkommodationsamplitude, monokulær akkommodationsfacilitet, nærfori, konvergensnærpunkt og positiv og negativ fusionsvergens. Ændringer i de målte parametre mellem de to undersøgelser blev beregnet, efterfulgt af en undersøgelse af om disse ændringer var korrelerede.

Resultater: Efter to år var der en signifikant forøgelse af afstandsvisus ($p = 0.04$), monokulær akkommodationsfacilitet ($p < 0.001$), exofori på nær afstand ($p = 0.04$), konvergensnærpunkt ($p = 0.01$) og fusionsvergens ($p < 0.001$), en signifikant reduktion i hypermetropi ($p < 0.01$) og monokulær akkommodationsamplitude ($p < 0.001$), mens midtpunktet for fusionsvergensen bevægede sig i mere konvergent retning ($p < 0.001$). Forøgelsen af konvergensnærpunktet var signifikant korreleret med reduktionen i den monokulære akkommodationsamplitude ($p < 0.001$), og det konvergente skift i midtpunktet af fusionsvergensen var signifikant korreleret med større fusionsbredde ($p < 0.001$). Alle øvrige parametre udviklede sig uafhængigt.

Konklusioner: Udvikling i refraktion, akkommodation og konvergens over to år var uafhængige. Dette kan skyldes at disse mekanismers udvikling reguleres separat og indikerer, at terapeutisk intervention kan foretages på disse parametre enkeltvis, uden afledt effekt på de øvrige parametre.

Introduction

The gradual decrease in hyperopia during growth of the eye in school children reduces the accommodative demand, which can in turn be expected to influence the coupling between accommodation and convergence (Goldschmidt, 1969; Schor, 2011). Therefore, in order to understand normal visual development and to design interventions for disturbances in this development there is a need to understand the coupling between refraction, accommodation and convergence.

Previous studies of school children aged 6–13 years have shown that the amplitude of accommodation decreases (Jimenez, Gonzalez, Perez, and Garcia, 2003), monocular accommodative facility increases (Scheiman, Herzberg, Frantz, and Margolies, 1988), near phoria changes towards convergence (Walline, Mutti, Zadnik, and Jones, 1998), near point of convergence recedes (Maples and Hoenes, 2007), and fusional vergence decreases (Lyon, Goss, Horner, Downey, and Rainey, 2005) simultaneously with the normal change in refraction (Bharadwaj and Candy, 2008). However, the interrelations between these parameters have only been scarcely studied. In a previous cross sectional study of school children from Denmark, we found independence of age dependent parameters describing refraction, accommodation, and convergence (Nisted, Maagaard, and Bek, 2013), but the interrelation between these parameters over time has not been elucidated.

Therefore, the aim of the present study was to investigate the interdependence of age-related changes in refraction, accommodation, and convergence over two years in a representative sample of Danish school children.

Methods

Design

A 2-year follow-up study of changes in refraction, accommodation, and convergence in a cohort of Danish school children.

Subjects

The baseline population consisted of 278 school children aged 7–13 years without manifest strabismus who were representative for 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 school per citizen and class size (2013).

Examination

Details of the baseline examination were described in (2013). The examination was performed at the school, and consisted of the following elements:

1. Monocular visual acuity at 4 m distance determined with a retro illuminated logMAR tumbling E chart with current correction if worn (Precision Vision Chart Illuminator, cat. no 2305).
2. Habitual spectacle correction when applicable using a Nikon OL-7 lensmeter.
3. Non-cycloplegic autorefraction performed with a Topcon RM-A7000 autorefractor. The average of three measurements of the spherical equivalent values were recorded for each eye.
4. Monocular amplitude of accommodation was measured twice using a RAF ruler by slowly moving a horizontal line consisting of 0.4/0.6 (logMAR 0.2) letters towards the child until the first sustained blur was reported.
5. Monocular accommodation facility measured at 40 cm for one minute using ±2.00 D accommodative flippers while the child viewed a horizontal line of 0.4/0.6 letters (logMAR 0.2), and the number of cycles per minute (cpm) was recorded.
6. Horizontal dissociated phoria at 40 cm using modified Thorington technique with a Bernell Muscle Imbalance Measure Card with a LED light (Bernell Corporation, USA).
7. Near point of convergence measured in centimetres using a RAF ruler and a vertical line which was moved slowly towards the child until diplopia was reported or loss of fixation observed.
8. Negative and positive fusional vergence measured at 40 cm while the child viewed a vertical 0.4/0.6 line of letters (logMAR 0.2) while demand on fusional vergence was gradually increased by use of a prism bar until either diplopia was reported or eye movement towards the base of the prism was observed.

Additionally, unilateral cover test was performed to exclude children with manifest strabismus.

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

Re-examination

The children were scheduled for re-examination two years later. Five children were absent on the day of examination, three declined to participate, and 48 children had moved to other schools. Six children were excluded because autorefraction showed myopia larger than -1.25 D while unaided distance visual acuity was 6/6 (logMAR 0.0) or better, suggesting excessive proximal accommodation. Therefore, statistical analyses were based on 216 (78%) children.

There was no significant difference in age ($p = 0.45$), sex ($p = 0.80$), or refraction at baseline ($p = 0.56$) between participants and non-participants. The baseline characteristic of the children who were re-examined were (mean (range)): Age: 9.9 (7.1–13.9) years and refraction: 0.15 (-11.25 – +6.00) D. It could be calculated that with this sample, the detection of changes in all variables could be obtained with a power of 80% at a significance level of 5%.

Data analysis

At each examination, fusional range was calculated as the sum of the numerical values of positive and negative fusional vergence, midpoint of fusional range was half the difference between the positive and negative fusional vergence. Subsequently, for all parameters changes from baseline to follow-up were calculated.

Statistics

All analyses were performed in Stata SE (StataCorp, USA) version 11. Age dependent parameters were identified by comparing baseline and follow-up data using both paired t-test and Wilcoxon signed-rank test. Since the conclusions were identical for the two tests, only results for paired t-test are reported. In order to investigate interdependences between changes in age dependent parameters, all changes in accommodation and convergence were compared mutually by simple linear regressions.

Supplementary testing using non-linear correlation with Spearman's Rank Sum Test resulted in the same conclusions. P-values below 0.05 ($t > 1.971$, df = 214) were considered statistically significant. Bonferroni correction was not appropriate since all comparisons were pre planned and tested a single hypothesis (Armstrong, 2014), and correction of the p-values did not alter the conclusions. Therefore, uncorrected p-values are reported. No statistically significant differences were found in changes of the parameters over time between sex, age, or refraction groups (hyperopia > +0.50 D, emmetropia from -0.50 to +0.50 D, and myopia < -0.50 D) using one-way ANOVA, and therefore data were not stratified. Only refraction and accommodation data from right eyes were reported since use of results from left eye or the average from the two eyes did not affect the conclusions.

Results

Figure 1 shows that at follow-up refraction was insignificant (-0.50 D – +1.13 D) in 80 percent of the children and that there was a slight change towards myopia.

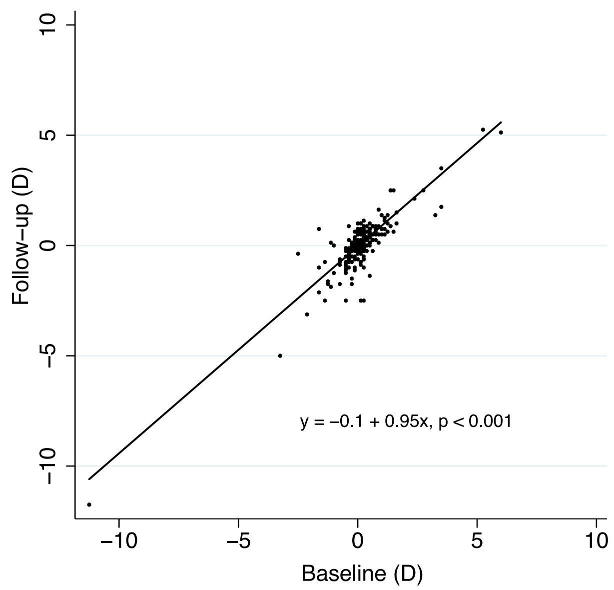

Figure 1: Autorefraction results (spherical equivalent) at baseline and follow-up.

Table 1 shows the changes from the baseline to the follow-up examination for all variables. It appears that there was a significant improvement in distance visual acuity and monocular accommodation facility, an increase in near point exophoria and fusional range, and a significant reduction in hyperopia and monocular amplitude of accommodation. A receding near point of convergence was found, while the midpoint of the fusional range changed towards convergence.

The interdependences between the age dependent parameters are shown in Table 2. It appears that the decline in near point of convergence correlated significantly with a decrease in monocular amplitude of accommodation and monocular accommodation facility. A convergent shift in the midpoint of the fusional range was significantly correlated with a larger fusional range. No other changes were significantly correlated.

Table 1: Baseline and 2-year follow for all variables at baseline and follow-up (mean, 95%-CI) (n=216)

	Baseline	2-year follow-up	p
Distance Visual acuity (logMAR)	0.02 [-0.01, 0.04]	0.00 [-0.02, 0.03]	0.04
Autorefraction Spherical equivalent (D)	0.15 [-0.01, 0.32]	0.04 [-0.14, 0.22]	0.01
Monocular amplitude of accommodation (D)	12.05 [11.60, 12.51]	10.86 [10.42, 11.30]	< 0.001
Monocular accommodation facility (cpm)	8.81 [8.15, 9.47]	11.01 [9.98, 12.04]	< 0.001
Near phoria (ΔD)	-0.84 [-1.27, -0.40]	-1.38 [-1.93, -0.83]	0.04
Near point of convergence (cm)	6.23 [5.79, 6.67]	7.15 [6.40 7.90]	0.01
Fusional range (ΔD)	29.82 [27.73, 31.92]	34.50 [32.68, 36.32]	< 0.001
Midpoint of fusional range (ΔD)	2.33 [1.64, 3.02]	4.35 [3.71, 4.92]	< 0.001

Discussion

To our knowledge this is the first study to examine the mutual dependence between changes in age dependent parameters describing refraction, accommodation and convergence simultaneously over time. The age of the participants was chosen to ensure that emmetropisation reducing the prevalence of hyperopia, myopia (Ingram and Barr, 1979), and astigmatism (Gwiazda, Scheiman, Mohindra, and Held, 1984) had ceased and that the change in the spherical component of the refraction could be expected to be maximal (Goss and Winkler, 1983). Furthermore, with the study of children of more than 6 years of age, visual acuity was expected to be sufficiently developed to give accurate feedback to the accommodative system (Evans, 2007). The validity of the results is enhanced by the fact that the examinations were performed on an unselected sample of school children using standardised methods previously shown to have high reproducibility in this age range (Casillas Casillas and Rosenfield, 2006; Scheiman et al., 1988). Although non-cycloplegic autorefraction has been shown to be biased towards myopia (Williams, Miller, Northstone, and Sparrow, 2008) a development in refraction over time was expected since only intra-individual changes were considered. The follow-up time of two years was sufficient to ensure time for the age dependent parameters to change significantly (Jimenez et al., 2003; 2004) but it cannot be excluded that a possible interdependence between some of the parameters may have required longer follow-up time to be identified.

The findings of age-related changes in visual acuity, refraction, monocular accommodation amplitude and facility, near point of convergence, and fusional range and midpoint, are in accordance with previous reports (2003; Lyon et al., 2005; Maples and Hoenes, 2007; Scheiman et al., 1988; Walline et al., 1998). Although previous results of age-related development in near phoria are conflicting, our findings are in accordance with the study on patients with the largest age range (Freier and Pickwell, 1983).

The observed correlation between fusional range and midpoint of fusional range would be expected since both variables were derived from negative and positive fusional vergence and only the latter changed significantly with age. Also, the observation of a receding near point of convergence with increasing age was correlated with the reduction in amplitude of accommodation which may be explained by the neurological coupling via accommodative convergence (Schor, 2011). The decrease in the amplitude and the increase in facility of accommodation with age are also consistent with previous reports (Jimenez et al., 2003; Scheiman et al., 1988), but the positive correlation between these parameters may be due to an amplitude of accommodation below what is required to stimulate accommodation. This may have resulted in blurred vision through the minus 2.00 D lens in a minority of the children. Thus, the correlation disappeared when the five children with amplitude of accommodation below 5 D were excluded from the analysis (p = 0.14). The age dependent decline in near point of convergence and improvement in monocular accommodation facility were

Table 2: Regression coefficients for independent comparisons of the studied variables (value, 95% CI) (n = 216)

	Autorefraction Spherical Equivalent (D)	Monocular amplitude of accommodation (D)	Monocular accommodation facility (cpm)	Near phoria (ΔD)	Near point of convergence (cm)	Fusional range (ΔD)	Midpoint of fusional range
Autorefraction Spherical Equivalent (D)	0.01 [-0.03, 0.04] p = 0.74	-0.34 [-3.93, 3.24] p = 0.85	0.51 [-3.87, 4.89] p = 0.82	2.01 [-1.37, 5.38] p = 0.06	1.12 [-1.77, 4.02] p = 0.48	-15.03 [-32.00, 1.93] p = 0.08	0.14 [-5.61 ,5.89] p = 0.96
Monocular amplitude of accommodation (D)		-0.19 [-1.21, 0.82] p = 0.70	-0.26 [-2.09, 1.56] p = 0.77	-0.41 [-1.22, 0.39] p = 0.31	0.26 [-0.87, 1.41] p = 0.65	-1.34 [-5.11, 2.41] p = 0.48	0.11 [-1.20, 1.42] p = 0.87
Monocular accommodation facility (cpm)			0.24 [0.00, 0.49] p = 0.05 †	-0.10 [-0.21, 0.01] p = 0.07	-0.30* [-0.43, -0.18] p < 0.001	0.42 [-0.07, 0.92] p = 0.10	0.08 [-0.10, 0.25] p = 0.37
Near phoria (ΔD)				0.03 [-0.03, 0.09] p = 0.34	-0.09* [-0.17, -0.01] p = 0.02 ‡	0.11 [-0.17, 0.40] p = 0.44	0.09 [-0.00, 0.20] p = 0.06
Near point of convergence (cm)					-0.06 [-0.25, 0.14] p = 0.57	-0.61 [-1.22, 0.00] p = 0.051	-0.01 [-0.23, 0.21] p = 0.91
Fusional range (ΔD)						-0.40 [-0.84, 0.05] p = 0.08	-0.02 [-0.17, 0.14] p = 0.82
Midpoint of fusional range							0.17* [0.13, 0.22] p < 0.001

Note. * = Significant p-value < 0.05. † p = 0.14 after excluding 5 individuals with abnormally low amplitude of accommodation (< 5D) ‡ p = 0.37 after excluding 5 individuals with abnormally low amplitude of accommodation (< 5D) correlated, but the correlation disappeared after adjustment for the amplitude of accommodation (data not shown), which is in accordance with the lack of known neurological coupling between the two parameters. Previous studies of myopia progression have found a correlation between refraction and amplitude of accommodation (Fledelius, 1981) or phoria (Gwiazda et al., 2004), which could not be reproduced in the present study and may be due to the low prevalence of myopia in the study population. Although exophoria will increase the demand on convergence, the slight increase in exophoria, which could be explained by an increase in interpupillary distance, was not correlated with the observed decline in near point of convergence and was not larger among children with the largest decline in near point of convergence (data not shown). This evidence suggests that exophoria might only be involved in the development of convergence insufficiency to a minor extent. A few of the comparisons were borderline significant and might become significant with longer follow-up time which should be tested in future studies.

Altogether, the results suggest that separate mechanisms regulate the development of the measured independent age dependent parameters. This is supported by previous findings which show that the occurrence of subnormal values of accommodative parameters do not coincide systematically with convergence insufficiency (Scheiman et al., 2011), that successful intervention on accommodative facility does not affect the amplitude of accommodation (Bobier and Sivak, 1983), and that two weeks of convergence exercises improve convergence but not accommodation in asymptomatic subjects (Horwood, Toor, and Riddell, 2014).

In conclusion, the study confirms known evidence about the development in refraction, accommodation and convergence parameters over time among school children, but the study also indicates that these changes are mutually independent. This suggests that clinical interventions can be performed on these parameters individually without affecting the other parameters, possibly reducing the duration of visual therapy required to obtain normal binocular vision for patients with convergence insufficiency. However, prospective interventional trials on each of these parameters are needed in order to support this assumption.

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