Independence between age-related changes in refraction, accommodation and convergence in primary school 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 –0.43 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 udviklingen i refraktion er associeret med udvikling i akkomodation og konvergens. 452 unselected 7-13-årige skolebørn fikk målt visus, unilateral covertest, autorefraktion, akkommodationsamplitude, monokulær akkommodationsfacilitet, nærophoria, konvergensnærheds punkt samt positiv og negativ fusionaloversynge. Linear 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 D/år, 95% CI [0.12, 0.74]) med alderen. Ingen af de aldersafhængige variable var signifikant internt korrelerede. Autorefraction var ikke signifikant korreleret med nogen af de øvrige variable. Aldersafhængige forandringer i refraktion, monokulær akkommoda-
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 re-
fraction of 0.07 D/year, in monocular accommodation facility of
0.2 cpm/year and in midpoint of fusional range of 0.4 ∆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 ex-
amination 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.

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 Illumi-
nator, cat. no 2305), with five tumbling E optotypes on each line.

- **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 contained:
  - Unilateral cover test at 6 m to detect intermittent and man-
    ifest 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 horizon-
    tal 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 verti-
    cal 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 frac-
  tion) letters. The position for first sustained blur was
  recorded.**

- **Negative fusional vergence and positive fusional ver-
  gence were measured at 40 cm with a prism bar with
  the subject viewing a vertical line of 0.4/0.6 (Snellen frac-
  tion) 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 val-
ues 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 Mi-
crosoft 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 covari-
ates between boys and girls, and therefore data were not strati-
ified by sex. Developmental trends were examined by simple lin-
ear regression comparing all variables with age. Subsequently
simple linear regression was used to compare all variables mu-
tually.

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 spheri-
cal 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 conclu-
sions. 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 reduc-
tion in hyperopia, a significant increase in the monocular ac-
commodation 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 vari-
ables with all other variables are shown in Table 3. It appears
that refraction was not correlated with any of the other pa-
rameters 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 in-
creased fusional range, larger amplitude of accommodation,
the present study was performed on a representative sample of school children in general because of inclusion of selected participants. The true association between refraction and parameters described in excess of 2 D is underestimated, partly due 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, Josue, & 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 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

| 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)‡ | 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

<p>| Table 3: Results from linear regression for mutual comparison of age-related variables with all other variables (regression coefficient, 95% CI, p-value). |
|----------------|----------------|----------------|----------------|----------------|----------------|</p>
<table>
<thead>
<tr>
<th>Distance visual acuity (logMAR)</th>
<th>Monocular amplitude of accommodation (D)</th>
<th>Near phoria (∆D)</th>
<th>Near-point of convergence (cm)</th>
<th>Fusional range (±D)</th>
<th>Midpoint of fusional range (±D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autorefraction, Sph (D)</td>
<td>-0.03</td>
<td>[-0.04, -0.01]</td>
<td>p &lt; 0.001†</td>
<td>0.10</td>
<td>[-0.20, 0.39]</td>
</tr>
<tr>
<td>Monocular accommodation facility (cpm)</td>
<td>0.00</td>
<td>[0.01, 0.00]</td>
<td>p = 0.54</td>
<td>0.02</td>
<td>[0.05, 0.19]</td>
</tr>
<tr>
<td>Midpoint of fusional range (∆D)</td>
<td>-0.00</td>
<td>[0.00, 0.00]</td>
<td>p = 1.00</td>
<td>0.15</td>
<td>[0.08, 0.22]</td>
</tr>
</tbody>
</table>

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

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References