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The amplitude of accommodation in 6–10-year-old children – not as good as expected!

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Abstract

The aim of this study was to measure the amplitude of accommodation for junior level school children and to compare it with age-expected values. A junior level school in Göteborg, Sweden, was randomly chosen and the amplitude of accommodation among 76 children aged 6–10 years was examined using Donders' push-up method. The results showed lower amplitude than expected in a large group of children. Results also showed lower amplitude than previously reported for this age group, especially under monocular conditions, which revealed an average dioptric difference from the expected value of −3.60 dioptres (D) right eye (mean 12.40 D, median 12.00 D, S.D. 3.7 D) and −3.50 D left eye (mean 12.50 D, median 12.70 D, S.D. 3.8 D) ($p < 0.001$ for both eyes). Consequently, we conclude that it cannot be assumed that the amplitude of accommodation is in the expected amplitude range for all children of these ages.

Keywords: accommodation, amplitude, children, insufficiency, subjective

Introduction

The data on the amplitude of accommodation presented by Duane in 1912 are still used as reference values today. Duane's data were compared with the amplitude data of Donders (1864) and Kaufman (1894) in a review by Hofstetter (1944). In 1950 Hofstetter, based on these data, suggested three equations, or linear relationships, for computing the minimum, maximum, and expected accommodative amplitudes for all ages based on monocular amplitude data. Unlike today, guidelines for making diagnostic accuracy studies (Bossuyt *et al.*, 2003) were not available at the time and consequently these studies lack a sufficiently scientific approach. In the study by Duane (1912) several essential issues that are unclear and/or not described in detail include the studied population (i.e. inclusion and exclusion criteria, and distribution of gender), how age was calculated, a description of the methodology, the number of measurements, and whether one or both eyes were studied in each individual. The measuring technique used (Donders push up technique) was discussed in later studies (Sheard, 1957; Woodruff, 1987). Sheard (1957) lists four different factors which introduce inaccuracies in Duane's method.

Despite the fact that the data originate from old studies performed without current scientific rigour, these data are still being used clinically as reference values for diagnosing accommodative insufficiency (AI). Morgan (1944) stated that AI occurs when the amplitude of accommodation is more than 2.00 dioptres (D) below Duane's expected value for an individual's age. Daum (1983) used the criterion of 2.00 D below Hofstetter's equation for the minimum amplitude by age. However, there is no consensus regarding the criteria for the diagnosis of AI. A recent study (Cacho *et al.*, 2002) gives a summary of nine different studies of AI – all with different diagnostic criteria; most, however, used criteria based on the equations presented by Hofstetter (1950).

Absolute values of the amplitude of accommodation are consequently based on data from old studies. Measurements on patients younger than 10 years of age are few and the trend in younger ages is unclear. Duane's data are from only 35 eyes in the age range of 8–12 years and the reliability of these data have been questioned (Turner, 1958; Wold, 1967; Kragha, 1986). The method of using a linear relationship as in Hofstetter's equations may also be questioned. If the relationship is linearly extrapolated a

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3-year-old child would have accommodative amplitude of 17.60 D, but we have very limited knowledge regarding accommodation at this young age. An extrapolation of Duane's data suggests very high accommodative amplitudes at a younger age and this essentially explains why younger children are often expected to have sufficient accommodative ability. As in adults, accommodative dysfunctions among children at any age may create near work-related problems. As AI does exist in children (Woodhouse *et al.*, 1993; Leat, 1996), as do near work-related problems, it was important to perform another study to re-evaluate accommodative amplitude in children. Woodruff (1987) measured accommodative amplitude in children between 3 and 11-years old. The data showed lower amplitudes in the younger age groups, increasing with age and peaking around the ages of 10–12 years. The relationship was described with a quadratic equation fitted to the data. This also implies that it may be inadequate to extrapolate Hofstetter's linear relationship to younger ages.

Furthermore, Berens and Sells (1944) stated that the accommodative system at a young age is quite flexible and resistant to fatigue. Although their data are old, this is still what is typically taught about ocular accommodation. Hence, the accommodative function is assumed to be powerful and full-scale at a young age and is often not examined. However, accommodative dysfunction does occur among pre-presbyopic patients in clinical practice. These patients often complain of symptoms that appear during work at close distance. As there is no consensus regarding diagnostic criteria or symptomatic accommodative level at various ages, the aim of the present study was to measure the accommodative amplitude in children aged 6–10 years and to compare our results with both Duane's data and Hofstetter's equations.

Materials and methods

Subjects

A junior level school in the Göteborg area was randomly chosen and all the children at this school were invited to participate in the study. Altogether there were 136 children in the age range 6–10 years in the school. All of the children were examined at school during school hours, that is, between 09:00 and 14:00 hours. No record was taken of whether a child was having a 'good' or a 'bad' day, and whether the children were measured before or after a tiring task. The study was approved by the Committee for Ethics at the Sahlgrenska Academy, University of Göteborg, Göteborg, Sweden. Informed consent was obtained from the parents.

Out of the 136 children, 28 declined to take part and 31 did not respond to the invitation to participate. Consequently, 77 children agreed to participate in the study and all were examined except for one boy who did not come for the examination. Four children (two girls and two boys) were excluded because of astigmatism > -0.75 D after the examination. Children with amblyopia, strabismus, or anisometropia would have been excluded, but none were found among the participating children. Consequently, the study included 72 children, 43 boys (mean age 8.1 years) and 29 girls (mean age 8.3 years). A demographic description is given in *Table 1*.

Table 1. The number and percentage of children aged 6–10 years examined (there were two grade 0 classes)

Grade	Age (years)	Girls (total *n*)	Boys (total *n*)	Examined girls (*n*)	Examined boys (*n*)	Examined children (%)
0 A	6–7	9	11	4	7	55
0 B	6–7	8	8	2	3	31
1	7–8	13	20	6	9	45
2	8–9	13	19	8	15	72
3	9–10	17	18	11	11	63
Total		60	76	31*	45*	56

*After the examination, four children (two girls and two boys) were excluded from the study because of astigmatism ≥ -0.75 D.

Methods

Examinations

A non-cycloplegic static retinoscopic refraction followed by a subjective refraction for distance correction and corrected visual acuity (VA) were performed. Visual acuity was determined at a test distance of 5 m, with the natural pupil and using the best distance correction. The officially approved Monoyer-Granström acuity chart, illuminated with approximately 700 cd m^{-2}, was used to determine decimal VA. The Monoyer-Granström is an acuity chart with Monoyer-built optotypes in arithmetical spacing. For determining VA at near, a Jæger chart for near was used.

Accommodative amplitude

Accommodative amplitude measurements were performed with Donders' push-up method using a Royal Air Force (RAF) Near Point Rule, a rod with a movable target and metrics, as well as dioptric markings. With the child wearing his/her best distance correction (i.e. the maximum plus lenses or minimum minus lenses that permitted maximum distance acuity vision when placed in a trial frame) the examiner placed the ruler on the center of the child's forehead. The child was required to read a line of letters that corresponded in size to 1.0 VA at distance and instructed to keep the letters clear. The target was slowly moved towards the child along the ruler until the child reported first sustained blur, at which point the dioptric result was recorded. Determinations were made both monocularly and binocularly, and all measurements were repeated three times. The average distance was recorded in D. When the dioptric result showed 20.00 D (i.e. the RAF ruler's truncation at this level), a suitable concave lens (−3.00 or −6.00 D) was added to the correction and a deduction was correspondingly made from the findings.

For a comparison, Hofstetter's equations for minimum, expected, and maximum amplitude by age (in years) was calculated (minimum = 15–0.25 (age (in years)), expected = 18.5–0.3 (age), maximum = 25–0.4 (age)).

Statistical analysis

Accommodative amplitude was plotted graphically together with Hofstetter's equations. The difference between the observed and those expected, according to Hofstetter's equation, was tested by Student's *t*-test. Corresponding confidence intervals (CIs) were calculated. The relationship between age and accommodative amplitude was analysed with Pearson's correlation coefficient. We used 5% as a level of statistical significance.

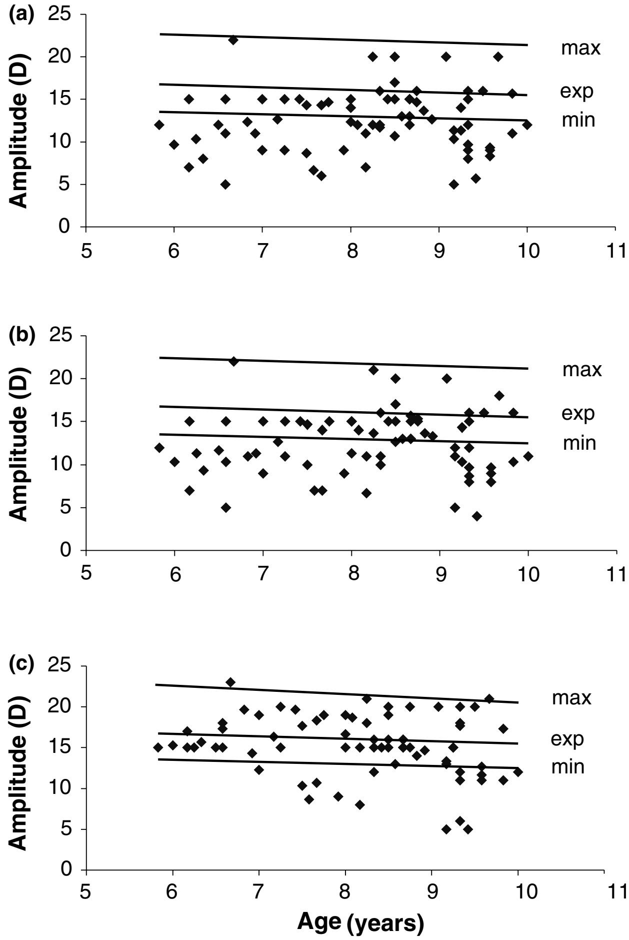

Figure 1. Right monocular (a), left monocular (b) and binocular (c) amplitudes of accommodation. Observed values (diamonds) in relation to Hofstetter's equations for minimum, maximum, and expected amplitudes (1950) (solid lines).

Results

Distance refractive error among the studied children revealed a median spherical equivalent of ±0.00 D (right eye) and +0.25 D (left eye). The lower quartile and the upper quartile were ±0.00 and +0.50 D, respectively, for both eyes. The maximum myopic value was −2.00 D and the maximum hyperopic value was +1.50 D. Visual acuity at distance was 1.0 for every single child. All children could read Jæger 1 at near, using their distance correction.

Accommodative amplitude

According to Hofstetter's equations, the reference values for accommodative amplitude are approximately the mean (expected line) and the maximum and minimum reference values, which Hofstetter calculated to be around 2 S.D. from the mean (1950). However, our data do not agree with the expected amplitudes as given by Hofstetter's equations (see *Figure 1a–c*) but show much lower values than expected. This was especially true for monocular measures which revealed an average difference from Hofstetter's expected of −3.60 D (−4.5, −2.8) (right eye) ($p < 0.001$) and −3.50 D (−4.4, −2.7) (left eye) ($p < 0.001$). The binocular measures were higher; nevertheless, the average difference from the expected line was −0.80 D (−1.7, +0.1) ($p = 0.072$). The results are summarized in *Table 2*. Therefore, we found statistically significant differences between our monocular data and those from Hofstetter's equations. The average difference of the binocular observations was not statistically significant. However, the observed power was only 0.45, and in this sense, the sample size was low. It should be mentioned that statistical tests compare groups of observations and sometimes it is unclear what a significance corresponds to in terms of a single individual. However, our findings are important at an individual basis as can be seen in *Figure 1a–c*. Around half of the studied children had monocular amplitudes

Table 2. Mean, median, and S.D. of the amplitude of accommodation in dioptres (D) and a comparison with expected values, according to Hofstetter's equation: expected amplitude = 18.5 – 0.3 (age)

Accommodation	Mean (D)	Median (D)	S.D.	Mean difference in observed vs expected values (95% CI)	*p*-value
Right eye	12.40	12.00	3.7	−3.60 (−4.5, −2.8)	<0.001
Left eye	12.50	12.70	3.7	−3.50 (−4.4, −2.7)	<0.001
Binocular	15.20	15.00	3.8	−0.80 (−1.7, 0.1)	0.072

Table 3. The proportion of children with accommodative insufficiency (AI) using different diagnostic criteria

	AI if accommodation is 2.00 D below the expected value (%)	AI if accommodation is below the minimum reference value (%)	AI if accommodation is 2.00 D below minimum reference value (%)
Right eye	62.5 (45/72)	56.9 (41/72)	33.3 (24/72)
Left eye	62.5 (45/72)	51.4 (37/72)	34.7 (25/72)
Binocular	29.2 (21/72)	22.2 (16/72)	11.1 (8/72)

lower than Hofstetter's minimum reference line [37 children (51%) with an amplitude below the minimum line in the left eye and 41 children (57%) in the right eye], and the children had amplitudes 0.50 D below the minimum reference line on average. Binocular amplitudes were more often above Hofstetter's monocular amplitude based minimum reference line, but a notable number of children were still below the minimum.

Naturally, the proportion of children with AI depends on the criteria for the diagnosis. *Table 3* gives the proportion of children with AI when different criteria are applied. Even the most conservative criterion, namely 2.00 D below the minimum line, rendered a fairly large proportion of children with AI (33.3% in the right eye, 34.7% in the left eye, and 11.1% for binocular accommodation). A result, which is important at an individual level, was that a large proportion of children were also below Hofstetter's minimum reference line. The proportion of children below the minimum reference line was fairly high, with monocular results being 56.9% (right eye) and 51.4% (left eye) and binocular results being 22.2%.

There was no significant correlation between age and monocular or binocular accommodation. Pearson's correlation coefficients were 0.10 (right eye), 0.05 (left eye), and −0.22 (binocular) ($p > 0.20$ in all instances). No obvious patterns could be seen in *Figure 1*. According to our data, the accommodative amplitude vs age relationship seems to be fairly flat for the age span 6–10 years.

Discussion

In 1912, Duane concluded that the amplitude of accommodation was high at a young age, and this has influenced clinical thinking about accommodative amplitude for many years. Even today the accommodative function is often not the primary function that is tested in an examination if a young person shows subjective symptoms when reading. The accommodative system is not routinely examined because of the assumption that accommodation is sufficient at a young age. In the present study we used Donders' push-up method to determine the amplitude of accommodation because it is commonly used to diagnose abnormalities of accommodation, particularly AI.

Regarding our individual data, the results presented are the average amplitude for three readings. Repeated measurements on each individual increases the intra-individual precision and it is common practice to calculate the average (McBrien and Millodot, 1986; Rosenfield and Cohen, 1996). In the study by Duane (1909) it is unclear how many measures the author took for each patient; however, it was clear that he also used the maximum value for each individual. For a comparison, we therefore used the maximum value of the three readings instead of the average, and recalculated all results. The differences were only marginal and did not affect the results and conclusions.

In *Table 4*, various earlier studies on accommodative amplitude in children are listed. Our study shows lower amplitudes of accommodation and systematic differences with expected values, according to Hofstetter's formulas, in a considerable number of children. The accommodative amplitude vs age relationship was also fairly flat in the examined age span. The minimum line is approximately 2 S.D. below the mean. Therefore

Table 4. The mean amplitude of accommodation from various earlier studies

	Age group (years)	Mean amplitude (D)
Donders (monocular)	10	19.70
Wold (monocular)	10	18.94
Turner (monocular)	'Under 13'	13.00
Eames (1961) (binocular)	8	13.70

around 2.5% of children are expected to be below the minimum line assuming that accommodative amplitude follows an approximately Gaussian distribution. A very low amplitude can of course be due to an accommodative spasm or a significant latent hyperopia. We did not use cycloplegia to measure the refraction in the present study. However, it is highly unlikely that a difference in distance correction from the cycloplegic refraction would explain the significantly low accommodative amplitude for the studied age group (Egashira *et al.*, 1993). It is also unlikely that many of our subjects would suffer from accommodative spasm as it is an uncommon clinical entity (Rutstein *et al.*, 1988). In fact Daum (1983) reports on 114 patients with accommodative disorders, but only three (2.6%) of the patients were diagnosed with accommodative spasm. Rouse *et al.* (1984), who determined the accommodative status in 721 school children using dynamic retinoscopy, reported that overaccommodation of 0.50 D or more occurred in only eight children (1%).

The different results between the monocular and binocular measurements in our study are in agreement with Duane's results, which showed similar differences between monocular and binocular accommodative amplitude, something that can be expected as binocular values are contaminated by vergence. The excess of binocular over monocular accommodative amplitude at the ages of 8–15 years was 0–6 D (Duane, 1922).

We do not know why so many children declined to participate or did not respond to the invitation. It is tempting to speculate on how a larger number of children would have changed our results. It is possible that parents encouraged their children to participate if they suspected them of having near vision or reading problems, which may have influenced our results. However, of the 72 children included, 16 (22.2%) had an observed binocular accommodative amplitude below the minimum reference line. Even if we assume that the 59 children who declined to participate all had values above the minimum reference line there would still have been 16 of 131 (i.e. 12.2%) who showed values below the minimum reference line. Consequently, despite a conservative calculation, a considerable proportion of the children would still have fallen below the minimum reference line.

The results from this study demonstrate that the amplitude of accommodation among a considerable number of 6–10-year-old children was lower than the expected amplitude for their age level. Whether these children also suffered from near work-related subjective symptoms that may be related to insufficient accommodation was also investigated and will be discussed in a parallel study (Sterner et al., personal communication). Nevertheless, the results of this study imply that there is a clinical need for examining accommodative amplitude as part of a child's eye examination. Expecting young children to have high amplitudes of accommodation may perhaps inhibit practitioners from making careful measurements of the accommodative amplitude, which, as Donders points out, is fundamental to making a sufficient diagnosis (1864). Monocular amplitude measures are important to determine whether a patient has AI whereas binocular amplitudes are influenced by vergence-induced accommodation. It would certainly be meaningful to perform longitudinal studies on the development of accommodative amplitude in children who are followed over time and also to examine the impact of alternative treatment methods in symptomatic patients.

It is important to diagnose accommodative or any other dysfunction. Therefore, it is essential to identify and possibly treat any accommodative deficiencies in young individuals as soon as possible after the start of school. AI has been associated with near point symptoms (Daum, 1983; Borsting *et al.*, 2003) and any accommodative deficiency can make it unnecessarily difficult for a child to read and develop in school. If the child does not alleviate or reduce its difficulties of accommodation he or she may always harbour a dislike for near distance work.

In conclusion, our results on accommodative amplitude in children between 6 and 10 years of age do not agree with Duane's data as described by Hofstetter's equations. One cannot assume that the amplitude of accommodation is high for children aged 6–10 years.

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