The accommodative process in children with cerebral palsy: different strategies to obtain clear vision at short distance

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AIM Accommodation is the ability of the eye to change focus in order to maintain a sharp image of objects at various distances. The accommodative process is largely unknown in children and requires new assessment techniques. The aim of the study was to investigate this process in children with and without cerebral palsy (CP).

METHOD In a descriptive case-control study, children with CP (n=15; nine females, six males; median age 14y) and 21 typically developing children (11 females, 10 males; median age 12y) underwent standard ophthalmological examination and examination by the PowerRefractor. Six of the children had spastic bilateral CP, five had spastic unilateral CP, and four had dyskinetic CP. The children’s Gross Motor Function Classification System (GMFCS) levels were as follows: level I, seven children; level II, two children; level III, three children; and level IV, three children. The PowerRefractor measures accommodation in response to minus lens stimuli. Continuous measurements of refraction/accommodation, eye position, and pupil size are obtained. The Kruskal–Wallis analysis of variance (ANOVA) and Mann–Whitney U test were used for between-group analysis (α=0.05), and Friedman ANOVA was used for within-group analysis.

RESULTS The stimuli–response gain (input/output) was approximately 80% in typical children inducing a focusing error (0.2–0.5D) increasing with minus lens power. Children with CP accommodated significantly less (gain: ~30%; p<0.001), inducing a larger focusing error (1.1–1.7D) increasing with minus lens power. The accommodative response was slower and more variable in children with CP. The pupil response did not mirror the accommodative response.

INTERPRETATION Children with CP exhibit problems in generating an appropriate accommodative response. This can affect everyday living and reading skills.

Accommodation is the motor command adjusting the refractive state of the eye by changing the shape of the crystalline lens through contraction of the ciliary muscle, that is accommodation enables the eye to focus at different distances (to obtain high visual acuity). The amplitude of accommodation can be assessed, and is measured in diopters (D). It can be as high as 15D in young children, enabling clear vision from distance to 6cm, but decreases with age, beginning to diminish as early as adolescence.

Synchronous with accommodation, the two eyes converge to correctly align the visual axes from both eyes onto the object of regard and the pupils constrict to increase the depth of focus. This combined response is usually termed the near triad as they normally occur in a coordinated manner.

The main stimulus to accommodation is typically visual blur. If the object of interest is held closer or further away from the plane of accommodation it will be perceived as blurred. To correctly adjust the plane of accommodation to another distance, the ciliary muscle receives neuronal input through the oculomotor complex.

Near work, such as reading a book requires active accommodation that is sustained during the entire task. A normal reading distance for an adult is 0.4 to 0.5m requiring an accommodative increase of 2.0D to 2.5D to see clearly. A child holds a book at a closer distance (about 0.3m), and thus needs to accommodate more (~3.3D). A normal accommodative response is, nevertheless, to slightly under-accommodate (called lag of accommodation) due to depth of focus. However, to read a text with a small font size requires more precise accommodation than reading a text with larger font size.

In cerebral palsy (CP) voluntary and automated motor control is affected to varying extent. Motor symptoms frequently found are paresis, spasticity, central dyscoordination, and co-contraction. In addition to motor and postural problems, many individuals with CP will have additional neurological conditions and a range of visual problems are
common. These visual problems include subnormal visual acuity, refractive errors, visual field defects, strabismus, nystagmus, abnormal saccadic movements, and cognitive visual problems, and are reported in 60% to 70% of children with CP. A few studies have investigated accommodation in children with CP. They report reduced accommodation when the accommodative response has been evaluated through different, mainly qualitative, methods. Duckman performed two studies in children with CP referred for visual problems. The first study investigated nine children with a subjective method where the speed with which the child could alternate between SD 2D lenses was evaluated. All children were reported to have accommodative problems. In the second study, 60 children were investigated and accommodative function was found to be ‘depressed if present at all’. Leat reports reduced accommodation in a group of ‘children’ with CP aged 3 to 35 years (mean, median, or SD of age not given). Dynamic retinoscopy, an objective qualitative method, was employed and greater than 40% of the children displayed lower than expected accommodative responses. Finally, a group from Northern Ireland investigated a population-based cohort of 90 children with CP with dynamic retinoscopy and near pupil response. They reported that the clinical subjective evaluation of near pupil response gives a rapid indication of the accommodative function and suggested that this can be utilized as a screening tool to identify children in need of a referral for a thorough optometric examination that includes accommodative functioning.

The aim of this study was to describe how children with and without CP obtain clear vision at short distance. In particular, the accommodative response with respect to time to accommodation, the amplitude of accommodation, and the lag of accommodation was studied. We also aimed to investigate the correlation of accommodation and near pupil response.

METHOD
Participants
In 2010 to 2012 a purposeful sample of children was recruited and examined as part of a descriptive case–control study. Children with CP were recruited from the neuropaediatric department at Astrid Lindgren Children’s Hospital, a tertiary clinic in Stockholm, Sweden, all of whom had undergone ophthalmological examination. The inclusion criteria were best corrected linear visual acuity of 0.65 or greater in the better eye and ability to understand instructions during the test procedure. Children with total hemianopia and with retinal pathology were excluded. The group included 15 children (nine females and six males) with a median age of 13 years and 10 months (range 10–18 by 5mo). Six of the children had spastic bilateral CP, five had spastic unilateral CP, and four had dyskinetic CP. Motor function was classified according to the Gross Motor Function Classification System (GMFCS) as follows: level I, seven children; level II, two children; level III, three children; and level IV, three children.

A control group of children with typical development was recruited among family and friends of the research group. The group included 21 children (11 females and 10 males), median age 12 years and 4 months (range 9y 7mo–17y 8mo). All children and their parents were given oral and written information about the study and thereafter consented to participation. The ethics committee at the Karolinska University Hospital approved the study and the study adhered to the Declaration of Helsinki.

Ocular examination
All children underwent an ophthalmological examination including visual acuity (KM linear letter chart at 40cm and at 3m), cover test and stereo acuity with TNO (random dot). Cycloplegic refraction was assessed with retinoscopy in all children with CP, and all but one had fundus photographs taken. All children had a normal-appearing macula. Two children with mild optic neuropathy were observed (hypoplasia and papiloedema).

Measuring accommodation and pupil response
The PowerRefractor (MultiChannel Systems, Reutlingen, Germany – currently manufactured by PlusOptix, Nürnberg, Germany) was used to measure oculomotor accommodation in response to step-blur stimuli induced by minus lenses. The PowerRefractor allows continuous measurement (25Hz) of refraction/accommodation (D), eye position, and pupil size (diameter in mm) and has been described in detail by Choi et al. During the measurements, the children watched a line drawn cartoon displayed on an iPod placed 1.14m from the eyes. The iPod was placed in the midsagittal plane next to the PowerRefractor sensor, allowing the same eye to both fixate and have its accommodation measured. Refraction/accommodation was obtained in one eye (the dominant eye).

For head stability and to maintain a constant distance between the eye and the PowerRefractor, a head and chin rest was used. Two examiners collaborated during data collection, one operated the PowerRefractor and one inserted minus lenses (accommodative stimulus). The lenses used were 0.0D, −1.5D, −2.0D, and −2.5D (in balanced order between children). The children were instructed to fixate and pay attention to the cartoon on the iPod and to keep the image clear and single. The same procedure was used in all children. The cartoon started and the child fixated the target binocularly for at least 10 seconds to obtain a steady-state level of accommodation. The accommodative stimulus was then inserted in front of both eyes for 15 seconds. After 15 seconds the lens was removed and the child was asked to maintain fixation at the target for another 10 seconds.

What this paper adds
- Children with CP exhibit problems in all aspects of the accommodative process: timing, amplitude, and stability.
- The greatest problems seem to be present in the group with dyskinetic CP.
- Pupillary constriction did not mirror the accommodative response and is thus unsuitable as a measure of accommodative function.
This cycle was repeated twice for each stimulus level. All children were pep-talked to regain clear vision when shifting lenses.

The accommodative data were filtered using a low-pass filter and plotted in OriginPro 8.0 (OriginLab Corp, Northampton, MA, USA). The baseline accommodation was adjusted to equal \( y = 0 \). The shape of the accommodative response to the step blur was modeled by a decay fitting function \( y = y_0 + A e^{-x/t_1} \). The time constant value \( t_1 \) calculates the time it takes to reach 63.2% of its final asymptotic value (i.e. stable accommodation). The asymptote \( y_0 \) calculates the average accommodative response obtained during stable accommodation, also giving the lag of accommodation. From these data the accommodative response in diptres, lag of accommodation (i.e. the difference between the accommodative stimulus and the accommodative response), time to reach stable accommodation, and stimuli–response gain (%) were calculated.

**Statistical analysis**
The calculated parameters were analysed within groups (0.0, 1.5, 2.0, and 2.5D) with a Friedman analysis of variance (ANOVA) and between groups (bilateral, unilateral, dyskinetic and typical) with Kruskal–Wallis ANOVA and Mann–Whitney U test. A correlation analysis was performed to evaluate the effect of GMFCS level and age on the parameters, as well as for the correlation between the accommodative and pupillary response using a linear regression model. Significance level was set to \( \alpha = 0.05 \) and all tests were two-sided.

**RESULTS**
Twenty-one children with typical development and 15 children with CP entered the study. One healthy child was excluded because of bad recording quality.

**Near visual acuity**
Best corrected visual acuity at near (and at distance) and refraction is presented in Table S1 (supporting information, published online). Children with CP had significantly lower near visual acuity than typically developing children (Mann–Whitney, \( p<0.01 \)). Group comparison (Kruskal–Wallis ANOVA) revealed close to normal visual acuities for the bilateral CP and unilateral CP groups, but considerably lower visual acuity in the dyskinetic group (\( p=0.01 \)).

**Accommodative response**
The accommodative base-line activity (i.e. no minus lens stimulation) displayed small regular fluctuations. Accommodation was more stable in the typically developing children \( (n=20; \text{median 0.45D \([25th–75th \text{centile 0.26–0.62}])}) \) compared with children with CP \( (n=15; \text{median 0.60D \([25th–75th \text{centile 0.32–1.00}])}) \). The minus lens stimuli induced larger accommodative fluctuations in all children, even in those children who did not accommodate to the blurry target.

The average accommodative response was calculated for each group and is presented in Table I and in Figures 1a and 2a. Children with CP accommodate significantly less than the typically developing group \( (p=0.001 \)) at all stimulus levels (1.5D, \( p<0.001 \); 2.0D, \( p=0.001 \); 2.5D, \( p=0.002 \)). No significant difference was found between the three groups with CP.

Further statistical analysis of the accommodative response (Friedman ANOVA) revealed a significant increase in accommodation to increased minus lens stimulation for the typically developing group \( (p=0.001 \)) and for children with bilateral CP \( (p=0.04 \)) but not for children with unilateral or dyskinetic CP.

**Pupil response**
The average pupil size before stimulation was 5.35 mm (SD 0.57mm) in the typical group and slightly smaller in children with CP (5.04mm, SD 0.63mm). The average pupil constriction to minus lens stimulation was calculated for each group. A significant difference was found between groups for the −2.0D stimulus \( (p=0.027 \) ), whereas −1.5D and −2.5D were close to significant. Children with unilateral CP revealed significantly more pupil constriction compared with children with bilateral \( (p=0.008) \) and dyskinetic CP \( (p=0.01 \); Figs 1b and 2b). There was a close to significant difference between children with unilateral CP and typical children. Typically

| Table I: Accommodative response (median [25th–75th centile]) |
|-----------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                 | 1.5D        | 2.0D        | 2.5D        | 1.5D        | 2.0D        | 2.5D        |
| **Typically developing** | 0.38  | 0.41  | 0.62  | 0.22  | 0.41  | 0.55  | 1.28  | 1.59  | 1.95 |
| \( (n=20) \) | (0.24–0.51) | (0.32–0.86) | (0.56–1.09) | (0.09–0.38) | (0.26–0.75) | (0.29–0.81) | (85.3) | (79.5) | (78) |
| **Group with CP** | 3.80  | 2.24  | 3.10  | 1.05  | 1.61  | 1.68  | 0.45  | 0.39  | 0.82 |
| \( (n=15) \) | (0.87–6.69) | (1.06–2.70) | (1.80–3.87) | (0.73–1.43) | (0.85–1.92) | (1.56–1.97) | (30) | (19.5) | (32.8) |
| **Bilateral CP** | 1.79  | 2.04  | 1.80  | 1.05  | 1.35  | 1.58  | 0.45  | 0.65  | 0.92 |
| \( (n=6) \) | (1.26–3.70) | (0.97–2.24) | (1.73–1.80) | (0.72–1.60) | (0.78–1.80) | (1.42–1.66) | (30) | (32.5) | (36.8) |
| **Unilateral CP** | 0.74  | 1.18  | 3.40  | 1.08  | 1.57  | 1.97  | 0.42  | 0.43  | 0.53 |
| \( (n=5) \) | (0.65–8.32) | (0.92–1.83) | (3.20–3.46) | (0.70–1.08) | (0.58–1.67) | (1.76–2.18) | (28) | (21.5) | (21.2) |
| **Dyskinetic CP** | 4.27  | 3.54  | 4.00  | 1.22  | 1.80  | 1.83  | 0.28  | 0.20  | 0.67 |
| \( (n=4) \) | (4.15–5.90) | (3.08–5.61) | (3.35–4.15) | (0.97–1.41) | (1.57–2.03) | (1.83–1.97) | (18.6) | (10) | (26.8) |

*Decay fitting not possible, stable accommodation is estimated by curve inspection, \( y_0 \) is calculated.
developing children reached a stable pupil position faster compared with children with CP (1.5D, \( p=0.003 \); 2.0D, \( p=0.012 \); 2.5D, \( p=0.017 \); for details see Table II).

**Influence of age and GMFCS level**
Age had no significant influence on accommodation or pupil response in the typically developing children.

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**Figure 1:** Display of recordings of the accommodative response (a, left) and pupillary response (b, right) for children with typical development. The first row (i) corresponds to -1.5D stimulation. Second row (ii) corresponds to -2.0D stimulation and the third row (iii) corresponds to -2.5D stimulation. (a) The stimulus was inserted (only the last 2 seconds before stimulation are displayed in the figure) inducing a defocus (positive shift in figure), triggering an accommodative response. The down-hill curve direct after 2 seconds corresponds to the accommodative effect of bringing a sharp image back on the retina. As can be seen, the defocus is not completely compensated for (i.e. lag of accommodation), which is a normal response. (b) The stimulus induced a pupil constriction that is seen as the negative shift of the curve at 2 seconds. Note the drift back of pupil position despite a steady accommodation.
Neither had age nor GMFCS level any significant influence on accommodation or pupil response in the group with CP.

**Figure 2:** Display of recordings of the accommodative response (a, left) and pupillary response (b right) for children with CP. First row (i) corresponds to -1.5D stimulation. Second row (ii) corresponds to -2.0D stimulation and third row (iii) corresponds to -2.5D stimulation. Black traces show average response for bilateral group, dark grey traces show average response for unilateral group and grey traces show average response for dyskinetic group. (a) As can be seen, in comparison with the typically developing children depicted in Figure 1, the accommodative response is lower, inducing a larger error (lag of accommodation), and it is more variable. (b) The pupillary response displays large variation between groups. Note the pronounced pupillary constriction in the unilateral group (dark grey).

**Correlation between accommodation and pupil response**

The maximal accommodative response (D) was analysed with the corresponding maximal pupil constriction (mm).
Table II: Accommodative pupil response (median [25th–75th centile])

<table>
<thead>
<tr>
<th>Time to maximum pupil response (s)</th>
<th>1.5D</th>
<th>2.0D</th>
<th>2.5D</th>
<th>Pupil constriction (mm)</th>
<th>1.5D</th>
<th>2.0D</th>
<th>2.5D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typically developing (n=20)</td>
<td>1.43 (1.01–2.15)</td>
<td>1.54 (0.70–3.09)</td>
<td>1.12 (0.84–2.09)</td>
<td>0.71 (0.36–1.00)</td>
<td>0.63 (0.45–0.76)</td>
<td>0.61 (0.42–0.84)</td>
<td></td>
</tr>
<tr>
<td>Group with CP (n=15)</td>
<td>1.85 (1.38–2.34)</td>
<td>1.54 (0.80–2.88)</td>
<td>1.68 (0.97–2.18)</td>
<td>0.49 (0.14–0.88)</td>
<td>0.33 (0.23–0.75)</td>
<td>0.41 (0.24–0.80)</td>
<td></td>
</tr>
<tr>
<td>Bilateral (n=6)</td>
<td>1.84 (1.04–1.85)</td>
<td>1.73 (1.20–2.01)</td>
<td>1.20 (1.18–2.35)</td>
<td>0.13 (0.16–0.21)</td>
<td>0.29 (0.25–0.42)</td>
<td>0.31 (0.23–0.40)</td>
<td></td>
</tr>
<tr>
<td>Unilateral (n=5)</td>
<td>1.87 (1.60–2.15)</td>
<td>0.93 (0.76–1.34)</td>
<td>1.12 (0.92–1.45)</td>
<td>0.92 (0.70–1.04)</td>
<td>0.98 (0.74–1.01)</td>
<td>1.05 (0.76–1.10)</td>
<td></td>
</tr>
<tr>
<td>Dyskinetic (n=4)</td>
<td>2.98 (1.43–4.51)</td>
<td>2.89 (1.56–4.88)</td>
<td>1.04 (0.94–2.29)</td>
<td>0.30 (0.30–0.60)</td>
<td>0.27 (0.04–0.42)</td>
<td>0.43 (0.35–0.47)</td>
<td></td>
</tr>
</tbody>
</table>

The coefficient of determination was calculated and the correlation found to be low, both in children with CP (1.5D, $r^2=0.23$; 2.0D, $r^2=0.008$; 2.5D, $r^2=0.18$) and in typically developing children (1.5D, $r^2=0.06$; 2.0D, $r^2=0.17$; 2.5D, $r^2=0.09$).

DISCUSSION

In this study we aimed to better understand the accommodative process in children with and without CP. The inclusion criteria applied were very strict, and thus the group with CP is not representative of all children with CP. Rather, only children with CP and high visual function were included. Despite this, we observed significant differences between children with CP and typically developing children with accommodation in children with CP being both slower and of lower amplitude.

The group with CP was selected because of normal or near normal best corrected visual acuity and normal or near normal visual fields in combination with an ability to cooperate in the test. Thus, children with visual impairment or with severe learning disabilities* were not included. The distribution of refractive errors in the study group differs from studies of larger groups of children with CP including. The distribution of refractive errors in the study group was low.

For the first time we were able to objectively demonstrate the accommodative and pupillary response in children with CP when subject to step-blur stimulation. The findings clearly demonstrate the absence of a distinct response and a reduced ability to accommodate in comparison with children with typical development. This finding confirms the results of a few earlier studies that found reduced accommodation among children with CP when using retinoscopy to evaluate the accommodative response.6–8

There are some interesting observations within the group with CP. The classification of CP into bilateral, unilateral, and dyskinetic types revealed significant differences between groups. Children with dyskinetic CP suffer from a poor accommodative response combined with a minor pupil constriction. The combination results in the lowest visual acuity at near. The group with bilateral CP has the best accommodative response combined with a poor pupil response. The opposite is found in the group with unilateral CP. This group was found to accommodate less and to constrict the pupil the most, on average 70% more than the typically developing group (–2.5D stimuli). Both the bi- and unilateral groups obtained a close to normal near visual acuity in clinical testing. Based on this limited number of data, it seems that children with CP administer different strategies to obtain clear vision at near; those who utilize a refractive change by increasing accommodation (ciliaris muscle) and those who utilize a higher degree of optical depth of field by pupil constriction (sphincter pupillae).

Dyskinetic CP is characterized by involuntary and uncontrolled movements. This is affecting a range of voluntary and automated movements and, as an example, this subgroup of children also has the highest prevalence of anarthria.15 The main reason is believed to be differences in injury mechanism; children with dyskinetic CP will, for the most part (75%), display basal ganglia/thalamic damage, whereas children with spastic CP often have a white matter damage of immaturity lesion.16 In our cohort, not all children underwent neuroradiological examination, but the four children with dyskinetic CP, all born at term or after (range of gestational age in weeks: 39 to 42+6) displayed basal ganglia injury. Our findings suggest that disturbances in basal ganglia control of eye movements as well as oculomotor function can affect voluntary and automated visual control in this group.

Analysis of the association between increased accommodation and pupillary constriction demonstrates poor correlation in both groups. Saunders et al.9 investigated the accommodative response through dynamic retinoscopy and compared the results with subjective grading of the near pupil response in children with CP. They classified the near pupil response as normal in 64%, reduced in 26%, and absent in 10%. In children in whom the pupil response was reduced or absent, significantly poorer accommodation was seen. The authors concluded that the near pupil response could be used as a rapid and effective indicator of accommodative function.7 The current study shows that many children will display a normal pupil response despite accommodative dysfunction, and that accommodation thus needs to be assessed in an objective way. Our findings are supported by other publications.17–20 In a study by Stakenburg17 in eight healthy children, there was a total absence of pupil constriction in a situation where the accommodation targets were accurately and carefully aligned along a single axis during a 2.5D ‘far-to near’ accommodative step paradigm. Another publication reports a 9-year-old male with

*North American usage: mental retardation.
Repeated assessments revealed 4D accommodation without any pupillary constriction. Phillips et al. investigated three healthy young males and reported that pupil response could be very much reduced or absent despite maintained accommodation response. They concluded that the changed size of the object of regard when moving from distant to near along with lateral or vertical displacement (changes in alignment), is most likely the provocation to pupillary constriction. Based on this we conclude that it is not possible to judge the accommodative response by observing only the pupil response.

The reduced accommodative function in individuals with CP may result in problems with near tasks. They may experience reduced visual acuity or blur, and images may be unsharp for a prolonged period after changing fixation distance. Some of the children with CP in this study also displayed a drift with loss of accommodation after the initial accommodative answer, even within the short 15-second frame of the study task. This indicates that an accommodation that needs to be sustained for a prolonged near task such as reading can actually be lost or fatigued early on in the task. It is known that children and adolescents with CP display impaired reading abilities relative to their cognitive level. However, visual function is typically not examined in studies assessing reading abilities in children with CP. Therefore, it is a reflection of the everyday clinical situation, when a more comprehensive visual assessment including visual field, crowding (i.e. better visual acuity to single letters compared with several equal-sized letters on a row due to visual perceptual problems), and accommodative function of the child with CP presenting with reading or other near task problems will not be performed.

In conclusion, children with CP display problems in generating an appropriate accommodative response. The largest problems are observed in the group with dyskinetic CP. This can impact everyday living and reading skills. Pupillary constriction did not mirror the accommodative response and is thus unsuitable as a measure of accommodative function.

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None of the funders have been involved in study design, data collection, data analysis, or any part of the manuscript preparation process.

SUPPORTING INFORMATION
Additional supporting information may be found in the online version of this article:

Table S1: Visual acuity and refraction in each group (median [25th–75th percentile]).

REFERENCES