

THE ACCOMMODATIVE PERFORMANCE OF INFANTS & YOUNG CHILDREN

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Abstract

Abnormal visual experience has been shown to lead to abnormal visual development. Abnormal visual experience in clinical terms is typically defined based on retinal image quality or retinal image correspondence. In addition to refractive error, retinal image quality depends on the accommodative performance of the patient. This review discusses studies of the development of accommodation in infants and their implications for the clinical assessment of young patients.

Key Words

abnormal visual experience, accommodation, infant vision, retinal image correspondence, retinal image quality, vision development

Many studies of animal models have shown that abnormal visual experience leads to abnormal visual development.¹⁻⁷ The primary clinical parallels to these manipulations are amblyopia and some forms of strabismus. Abnormal visual experience in this context is either poor retinal image quality or poor retinal image correspondence.

Clinically, we worry about poor retinal image quality for patients with pathologies such as cataract or ptosis and for patients with refractive problems such as defocus or astigmatism. These patients are likely to develop amblyopia. Retinal image correspondence is disrupted in strabismus and is associated with the loss of binocular function. Once these patients have developed these neural abnormalities, current approaches to their clinical management are also grounded in the manipulation of visual experience, through patching and atropine for amblyopia, or eye alignment with surgery, prisms or vision therapy for strabismus. Much is being learned about cortical synaptic plasticity in the context of long-term potentiation (LTP) and depression (LDP).⁸ However, pharmaceutical approaches to the widespread manipulation of cortical synapses have not yet been developed as an alternative to the manipulations of visual experience.

While poor retinal image correspondence can be detected relatively easily, in that many forms of strabismus can be noticed by the layperson, the assessment of retinal image quality is notably more complex. Optical aberrations, such as hyperopia, anisometropia or astigmatism are not detected when merely observing a patient. Therefore, amblyopia and any associated refractive anomalies can develop almost

silently. In fact, anisometropic amblyopia or bilateral, isoametropic amblyopia are commonly not detected until an eye examination or vision screening is performed. Progress in our understanding of the natural history of these forms of amblyopia has been limited by this problem. Does the human condition literally parallel the manipulations used in the studies of animal models? As a result of our limited understanding, as yet, we only have consensus-based guidelines for prescribing for hyperopia in apparently asymptomatic infants and children.^{9,10} Large numbers of infants and young children need to be studied longitudinally to find the affected individuals and to develop evidence-based prescribing guidelines.¹¹⁻¹³ In addition, however, abnormal visual experience defined in terms of retinal image quality is not solely defined by refractive error. Particularly in the case of hyperopic patients, the defocus component of habitual retinal image quality is actually defined by their accommodative performance.

In the absence of evidence based guidelines for prescribing for hyperopia, the goal of this review is to provide a current understanding of the development of accommodation to enable a clinician to consider the quality of a patient's accommodative performance in their decision to prescribe optical correction.

Accommodative performance in infancy

The early studies of young infants' accommodative performance were conducted using retinoscopy and photorefractometry.¹⁴⁻¹⁹ The approach was to present young infants with a stationary target at a specified viewing distance and then determine how accurately the infant was able to focus on the target. The consensus from this series

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of studies was that infants, less than approximately two months of age, tend to over-accommodate for distant targets and under-accommodate for very close ones. They tend to maintain their focus around an intermediate distance even though they are typically hyperopic. Hainline, Riddell, Grose-Fifer and Abramov¹⁵ noted that a number of infants less than two months of age typically focused at around 30 cm, for example, and Haynes, White and Held¹⁴ found a median distance of 19 cm for infants of less than one month of age. It is also apparent that at around three months of age infants begin to modulate their accommodation to different distances more effectively. Looking at the data of Banks¹⁷ for example, one infant maintained a mean accommodative focus of between 1.75 and 2.75 D for stimuli between 1 D and 4 D at five weeks of age. These data were collected with retinoscopy and were not calibrated for absolute defocus. Nevertheless, it is apparent that the infant was changing focus minimally for stimuli at different viewing distances at that age. By nine weeks however the infant was following the stimuli more closely and exhibiting a measured lag of less than 0.5D for each one.

What might underlie this development in the first months after birth? Models of the accommodative system are often characterized in three parts: the sensory system responsible for encoding the blur or other cues in the retinal image; the neural processing that is responsible for developing a motor plan for the accommodative response; and the mechanical plant that is responsible for implementing the proposed response. In these terms, is a young infant unable to encode blur, or program a response, or make the motor response? Haynes et al¹⁴ noted that sleeping infants of less than one month of age exhibited, on average, five diopters less accommodation than when they were awake and alert. It is also the case that infants are typically found to be hyperopic with cycloplegic refraction, while they are found to be focused at near distances when fixating on a more distant target as described above. These data, therefore, do not support the hypothesis that the motor plant is unable to make a motor response.

Green, Powers and Banks²⁰ conducted an analysis of accommodative responses that suggested the immaturity might lie in sensory processing. They asked how sensitive infants were to blur and whether they would be able to detect that they were not

accommodating accurately. They calculated an estimate of blur tolerance, or depth of focus, based on pupil size and acuity. A number of assumptions had to be included in this model, including the idea that the same processes that limit behavioral acuity limit the performance of the accommodative system. Nevertheless, the predictions were relatively close to the actual performance observed for one-, two- and three-month-olds and adults. This supports the notion that young infants do not change their accommodation dramatically in response to changing stimuli because they are not sensitive to the induced level of blur. Once they become more sensitive to blur they may start to accommodate more accurately to the different stimuli.

While the results regarding accommodation to stationary targets at different distances appear consistent, one must remember that conclusions regarding the absolute value of the estimated retinal defocus are not as straightforward. The retinoscopy and photorefraction techniques are both dependent on reflection from the retina, and provide an estimate of defocus relative to that plane. In reality, the sensory system is encoding blur based on information encoded at the photoreceptors and therefore, any mismatch between the average plane of reflection and the plane of the photoreceptors will result in an error in the estimate of defocus. Is this error likely to be large? In an adult eye, 1mm of depth at the retina is approximately equivalent to 3D of defocus for an average axial length. The retina is approximately 250 microns thick²¹ and therefore a reflection from the inner limiting membrane could, in theory, introduce an error in the estimate of approximately 0.75D. It is more likely that the reflection comes from a deeper layer than the inner limiting membrane, however, and so this is likely to be an upper estimate on the error. The infant eye is two thirds of the length of the adult eye, and therefore, if everything scales proportionally, this would equate to an error of a little over a diopter (see²² for further discussion of this question). Thus, firm conclusions about small amounts of absolute defocus and the accuracy of accommodation cannot be drawn until we have a better understanding of the reflective properties of the retina in relation to the position of the photoreceptor layer.

Overall, these data suggest that young infants should be able to accommodate relatively well to a stationary target. In fact

their relative accuracy is almost adult-like by three or four months.¹⁴⁻¹⁶ Does this mean that accommodative performance is fully adult-like at that time? This conclusion also depends on the dynamics of infants' accommodation. Are they able to maintain their accommodation on a stationary target, or is their focus unstable and fluctuating? How quickly can infants change their focus? Are they able to track moving objects, or are they likely to experience chronic defocus because they cannot keep up with their dynamic environment?

The first data regarding the dynamics of infants' accommodation were provided by Howland, Dobson and Sayles.²³ They used photorefraction. In this technique, the eye's defocus is derived from the reflex in the pupil in a single image, rather than being averaged over sweeps of the beam).²⁴ Consequently, the infants' responses were sampled at a faster rate. They plotted the responses of two infants (4.5 and 9 months of age) whose responses were collected twice per second. These infants were able to initiate and complete accommodative responses within one second of the stimulus change. Tondel and Candy^{25,26} also used photorefraction to look at a series of infants to determine whether younger infants demonstrated the same dynamics and how their responses varied as a function of stimulus velocity. We found that at 8 weeks of age more than half of the recorded responses had response latencies of less than 0.5 sec, and that the infants could adjust the velocity of their response to track stimuli moving at 50, 20 and 5 cm/s. As an illustration, Figure 1 presents data recorded recently in our lab, demonstrating the responses of a four-month-old infant in comparison with a two-year-old. The data were collected with the Multi Channel Systems PowerRefractor, at 25 Hz. The stimulus is shown as a solid line and the accommodative responses of the right eyes of the subjects are shown in black and grey, respectively. The responses have been shifted vertically for clarity, but each step on the y-axis is equivalent to 2D. These data are typical for these ages in our experience.

Figure 1 also illustrates that these infants are able to keep their accommodation relatively stable for a stationary target. Candy and Bharadwaj²⁷ performed an analysis of the fluctuations of accommodation of young infants and determined that infants from 8 to 30 weeks of age tend to have fluctuations with the same

The dynamics of accommodation of a 4-month-old and a 2-year-old

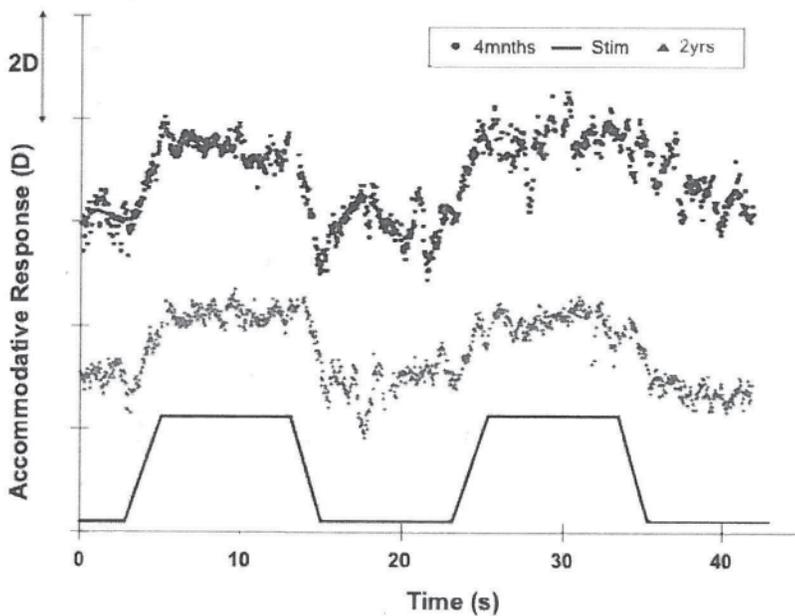


Figure 1. The accommodative responses of the right eyes of two young subjects. The data were collected using photorefracton at 25Hz, and have been shifted vertically for clarity and comparison.

characteristics over time as adults, but with twice the amplitude (the adults had a root mean square error of approximately 0.15 D, and the infants had a value of approximately 0.35 D).

Thus, in summary, young typically developing patients should be experiencing retinal image quality that is close to the adult level when they are actively engaged in a task. They should have a lag measured to be on the order of 0.5 to 1D, be able to change their accommodation rapidly, and be able to sustain their response on a target relatively accurately. They should be able to do all of this by four months of age.

How well are we able to assess this in the clinic, and what should we consider abnormal?

Clinical assessment of accommodation

Although the absolute accuracy of the retinoscopy and photorefracton techniques is not fully understood at this point, as a result of the characteristics of retinal reflection,²² we can still measure the apparent defocus of the eye using these techniques and compare it with norms for an age group. The comparison with these norms is not only dependent on the range of accommodative responses across the population, but also the repeatability of the technique. Do we get the same result when we measure the same thing twice? The repeatability of retinoscopy is not

considered to be very good, and autorefractors can be found to be somewhat better.²⁸ However, it is not always possible to generate a near stimulus at a desired distance when using an autorefractor, and most clinical assessments of accommodative performance are typically done using either Nott retinoscopy or monocular estimation method (MEM). Although other methods are available, they are also not as easily affected by reflections from lenses and small pupil sizes.

The design of the stimulus is another important factor influencing the accommodative lag measurement. Two approaches can be taken in choosing a stimulus. Typically a clinician will use a target that is close to the subject's acuity limit, to drive the patient to accommodate to the best of their ability. An alternative strategy is to provide them with a target that more closely represents their habitual environment; a target with broad spatial frequency content, such as a sticker showing a cartoon character that can be discussed with the patient during the test. In this case the patient may reveal a lag that they exhibit in habitual conditions, in that they are not being asked to perform fully maximally during the short test.

A number of studies have looked at developing norms for accommodative performance in young patients. For example, Rouse, Hutter & Shiftlett²⁹ used MEM to examine the performance of 721 children

from kindergarten to sixth grade. The subjects held a book at their own reading distance and, overall, their mean lags were found to be a third of a diopter, with a standard deviation of another third of a diopter. There was a small effect of age. Leat and Gargon³⁰ used Nott retinoscopy with back-illuminated pictures and found that three- to ten-year-olds exhibited a mean response within 0.50D of the target and a standard deviation of less than a diopter for stimuli further than 12 cm from the subject. McClelland & Saunders³¹ also used Nott retinoscopy with illuminated pictures and found a mean lag of a third of a diopter with a standard deviation of a third of a diopter for a four diopter target demand. They had tested children from four to fifteen years of age and found no effect of age. These data are also in good agreement with those of Chen and O'Leary.³²

If these are the data for typically developing children, what might be considered abnormal? Firstly, McClelland & Saunders³³ also performed a study of the repeatability of the Nott technique and found that 95% of repeated measurements lay within $\pm 0.56D$ of the first measurement for a four diopter target demand. Their subjects were between 6 and 43 years of age and therefore it is not clear what the corresponding value would be for younger infants and children.

Two groups of patients have received particular attention because they have been found to have limited accommodative performance. Children with Down syndrome and children with cerebral palsy have both been found to have large accommodative lags.³⁴⁻³⁸ The reasons for this are not fully understood. Still, there is now evidence that accommodative performance should be assessed clinically for these patients, and that optical correction may be useful for nearwork.³⁹ The presence of hyperopia in addition to reduced accommodative performance would put these young children at particular risk for amblyopia.

In looking at more general populations, there have been a number of interesting observations made in the literature. Rouse et al,²⁴ based on their mean and standard deviations of a third of a diopter, suggested that any lag greater than 0.75D should be explored further. Hunter⁴⁰ has noted that some pre-verbal patients will exhibit large lags and has recommended that accommodative performance should be checked routinely when making decisions about prescribing for hyperopia in

young children who are at risk for amblyopia.

Ingram, Gill and Goldacre⁴¹ conducted a prospective longitudinal study of a large number of infants. They noted that a number of hyperopic infants who went on to develop strabismus had relatively large accommodative lags prior to the onset of the deviation. The retinoscopy technique used to assess accommodative performance in that study is not a standard technique and therefore it is not easy to interpret those data quantitatively in the context of more commonly used clinical techniques. This result is particularly interesting though, in that it is somewhat counter-intuitive. When considering two hyperopes with equal refractive errors, one might predict that the individual who accommodates more might drive over-convergence leading to strabismus. Ingram et al found the opposite result; it was the infants who had the larger lags who developed the strabismus.

In summary, patients with non-strabismic accommodative disorders are commonly diagnosed at an age where they can make reliable subjective responses and describe symptoms. However, we now have evidence that younger infants and children should be accommodating with almost adult like lags for typical targets. Therefore an apparently large lag at younger ages can more confidently be considered abnormal and a sign that this patient may be at risk for amblyopia or strabismus as a result of their abnormal visual experience. These patients are still in the critical period for cortical synaptic refinement and so their retinal image quality should be considered in that context, in addition to their ability to perform their daily tasks.

Note

The author has no proprietary interest in any of the equipment used in this study.

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