Special Issue

IMI Accommodation and Binocular Vision in Myopia Development and Progression

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The role of accommodation in myopia development and progression has been debated for decades. More recently, the understanding of the mechanisms involved in accommodation and the consequent alterations in ocular parameters has expanded. This International Myopia Institute white paper reviews the variations in ocular parameters that occur with accommodation and the mechanisms involved in accommodation and myopia development and progression. Convergence is synergistically linked with accommodation and the impact of this on myopia has also been critiqued. Specific topics reviewed included accommodation and myopia, role of spatial frequency, and contrast of the task of objects in the near environment, color cues to accommodation, lag of accommodation, accommodative-convergence ratio, and near phoria status. Aspects of retinal blur from the lag of accommodation, the impact of spatial frequency at near and a short working distance may all be implicated in myopia development and progression. The response of the ciliary body and its links with changes in the choroid remain to be explored. Further research is critical to understanding the factors underlying accommodative and binocular mechanisms for myopia development and its progression and to guide recommendations for targeted interventions to slow myopia progression.

Keywords: accommodation, binocular vision, myopia development, myopia progression, emmetropization

The association between sustained near work demanding high levels of ocular accommodation and the development of myopia has been well documented.[1] Epidemiologic studies have also shown a correlation between the amount of near work and the onset and progression of myopia.[2–4] Consequently, increased accommodative effort required during near work has been proposed as a causative factor in the development of myopia. However, the relationship between accommodative demand and myopia is complex. Due to the synergistic response of the vergence system, the status of binocular vision at near work also varies with accommodation, yet the impact of heterophoria at near work on myopia onset and progression is not fully understood. This article provides a comprehensive review of the research evidence on the influence of accommodation and binocular vision in myopia development and progression; it also translates the current evidence and main findings to clinical practice.

VARIATIONS IN OCULAR STRUCTURE DURING ACCOMMODATION

Owing to the purported links between accommodative dysfunction and myopia, investigations of structural and functional differences in the accommodative apparatus and associated ocular elements are of particular interest. One of the broader academic and clinical motivations driving such endeavors is the opportunity to elucidate structural variations or trends that may be predictive of specific patterns of myopia progression, for example, in identifying those at particular risk of the onset of myopia, high myopia, or rapid progression of myopia.

To facilitate the understanding of how and why the structure of a myopic eye may affect accommodative behavior, the following section presents a brief review of the mechanism of human accommodation. Although the literature stands equivocal concerning the exact mechanism, it does

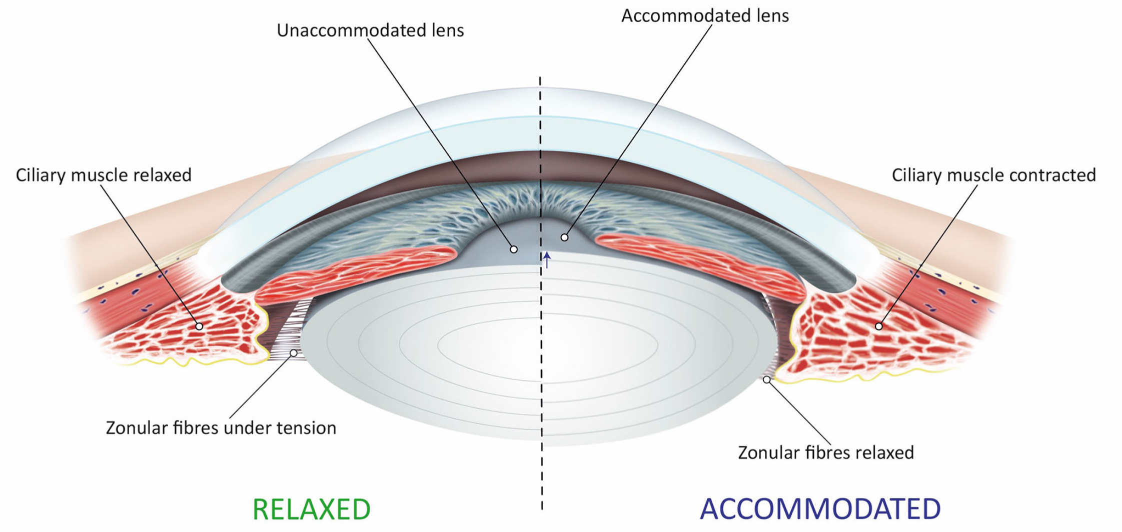

Figure 1. Differences in anterior eye structure in the relaxed (unaccommodated) and accommodated eye. Copyright © 2021 by IMI.

largely acquiesce to a Helmholtzian model of accommodation (1855). In this model, the ciliary muscle (a smooth muscle ring) is in a relaxed state while viewing an object at optical infinity. As the apex of the ciliary muscle has a relatively large diameter in this state of relaxation, the anterior zonular fibers from which the crystalline lens is suspended are maintained under tension due to strain from the posterior pars plana fibers. Consequently, the stretched anterior zonules exert strong radial forces on the capsule and flatten the crystalline lens. When the eye shifts focus to a near target, the ciliary muscle contracts, moving its mass anteriorly and centripetally and releasing tension on the zonules. Helmholtz proposed that this structural change occurs because the capsule and the lens matrix are inherently elastic; when freed from the zonular pull, the lens, with the aid of its capsule, can assume an axially thicker[5–16] and rounder shape, with a reduced diameter.[17–22] Refractive change during accommodation is primarily attributable to an increase in anterior surface curvature of the crystalline lens surface[5,23,24] and a simultaneous smaller increase in posterior surface curvature.[6,25,26] These dimensional changes result in a reduction in anterior chamber depth, yet overall an increase in anterior segment length (distance from the cornea to the posterior surface of the lens).[10,12,27] Once accommodation ceases (Fig. 1), the ciliary muscle is thought to return to its relaxed position as a result of elastic recoil imparted by the choroid.[28]

Despite the advent of high-resolution and dynamic ocular imaging systems allowing visualization of many previously unknown anatomic subtleties, the iris still prevents imaging of the key accommodative structures. These limitations also apply to studies attempting to determine whether accommodative mechanics differ as a function of ametropia. Consequently, at present, several models exist, with varying levels of evidence regarding accommodation induced structural changes that may be instrumental in myopia onset and progression.

It is well documented from biometric studies that increased vitreous chamber depth is the primary structural change in the majority of cases of myopia,[29] and that myopic eyes are generally globally larger and longer than emmetropic eyes.[30,31] The literature also reports other differences in ocular structure as a function of ametropia, including corneal curvature[32–35] anterior chamber depth,[36] crystalline lens thickness,[37–39] choroidal thickness,[40] and scleral rigidity.[41,42] The anatomic complexities of each of these structures in relation to accommodation and refractive error give rise to potential corollaries for accommodative performance and myopia progression.

The first consideration is the nature of global eye size in terms of the optics of the eye and the implications for accommodative performance. Davies and colleagues[43] explained using ray tracing that axially myopic and axially hyperopic eyes show different vergence contributions for light rays entering the anterior segment. They attributed this optical behavior to a consequence of “natural damping” associated with negative vergence and axial length changes. The spectacle corrected myope also has to accommodate and converge less for a near target than an emmetrope does due to the prismatic effect of the lenses.[44] Therefore, accommodative response for a similar demand will be slightly greater in a longer (myopic) eye compared to a shorter (hyperopic) eye due to differences in eye size.

CHANGES IN THE ANTERIOR SEGMENT IN RELATION TO ACCOMMODATION AND MYOPIA

Pupil Size

Given the evidence that axial growth is influenced by visual experience inclusive of retinal image quality and optical defocus[45–48] and data suggesting that myopes display unusually high levels of aberration and/or larger accommodative lags relative to those who remain emmetropic,[49–59] the role of the pupil in myopigenesis is unclear. As the pupil acts as an aperture stop, theoretically, inter- and intra-individual pupil size variations present a potential innate and dynamic physiological mechanism whereby optical image properties, including retinal image blur, higher-order aberrations, depth of focus, and accommodative lag, could differ between myopes and nonmyopes or fluctuate in a myopigenic fashion over time contributing to progression in susceptible individuals.[60] Generally, larger pupil diameters lead to greater wave-front aberrational blur,[61] whereas during accommodation, the blurring effect of a given dioptric lag would be proportionally greater due to the larger retinal blur circle diameter.[60]

Nonetheless, most human studies have failed to find significant differences in unaccommodated pupil diameter between age-matched emmetropic and myopic groups.[60,62–65] A few studies have reported a weakly associated increase in pupil diameter in myopes, but these studies have important design limitations, including differences in target distance[66] or age[67] between groups. Further, anecdotal evidence supporting a lack of correlation can be drawn from numerous studies that report isocoria in anisometropes, which is counter to expectation should more myopic eyes have systematically larger pupils.[60,68] Differences in pupil size or response during steady-state accommodation or the notion of systematically higher levels of retinal image blur in myopes with larger pupils are also unsupported by in vivo data.[60,65]

It would therefore seem plausible that pupillary characteristics in accommodated and unaccommodated eyes are independent of ametropia and the notion that pupil-related factors play a role in myopia genesis is currently unsubstantiated. It should, however, be noted that the aforementioned studies show considerable variations among individuals, generally examine adult populations, and do not differentiate between progressive and stable myopia. It has been suggested that different trends may be evident in more homogenized refractive error or age groups, particularly pediatric populations.[60]

Ciliary Muscle

As ciliary muscle contraction is a prerequisite to accommodation,[69] interest in morphological differences in ciliary muscle anatomy has increased[70] in the context of how they may contribute to the association between nearwork and myopia. In the unaccommodated state, myopic children[71–74] and adults[75–79] have been shown to have thicker ciliary muscles in the posterior-most aspect, typically 2 to 3 mm behind the scleral spur,[70,71,73–76,78] with thickness correlating positively with increasing axial length. Meanwhile, some studies have also reported a thinner anterior portion of the ciliary muscle in axially longer eyes.[73,79,80] In hypermetropic children, the ciliary muscle shows its maximum thickness anteriorly, approximately 1 mm from the scleral spur.[73] Interocular differences have been reported in anisometropia, with significantly thicker muscles observed in eyes that have unilateral high myopia compared with the fellow eye.[76] Furthermore, region-specific differences in thickness have also been reported, with the longitudinal fiber portion being thicker and the apical fiber region being thinner in the more myopic eye.[79] Nonetheless, Sheppard and Davies[81] found a positive correlation between axial length and ciliary muscle length, but not between axial length and ciliary muscle thickness when considered as distances from the scleral spur as a percentage of the total length of the ciliary muscle.

Studies examining general ciliary muscle morphology under various accommodative demands,[77,81–85] have suggested a linear relationship between ciliary muscle thickness and accommodative response,[74,82,86] showing that the muscle thickens anteriorly and thins posteriorly with increasing accommodative effort.[74,81,82] Sheppard and Davies[81] and Lewis et al.[74] examined accommodation-induced morphological changes between refractive groups and found no dependence of the ciliary muscle accommodative response on axial length or ciliary muscle baseline thickness. Interestingly, Jeon et al.[77] reported reduced movement of the ciliary muscle during accommodation in individuals with increased axial length and ciliary muscle thickness. However, as accommodation responses were not assessed, it remains unclear whether there was a smaller relative change in crystalline lens thickness per unit of accommodative response for eyes with longer axial lengths,[43] or whether there were functional consequences (e.g. increased lag).

Although it is clear that differences in ciliary muscle anatomy between myopes and nonmyopes exist, if or how this would translate into a myopigenic effect remains undetermined. Only minor differences in accommodative behavior (optical coherence tomography [OCT] assessed microfluctuations of accommodation, velocity of accommodation and disaccommodation, and lag of accommodation) occur between emmetropes and myopes despite the morphological differences between them,[86] suggesting that ciliary muscle size may not be a contributing or critical factor in myopia development. Nonetheless, other models have been proposed.

One early suggestion is that the ciliary muscle tonus could in turn affect choroidal tension, resulting in axial length change (see later section regarding transient axial elongation).[87] Alternatively, a thicker ciliary muscle might prevent the equatorial stretch, which can occur with myopia and thus maintain emmetropia, thereby being a factor in myopigenesis.[88] However, a myopic shift in refraction has been found not to be associated with a change in ciliary muscle thickness over time in children.[89] A hypertrophic ciliary muscle could theoretically lead to myopia development, perhaps due to poor contractibility resulting in accommodative inaccuracies and chronic retinal hyperopic defocus under nearwork conditions. Seemingly, the evidence that children and adults with myopia have higher accommodative lags than emmetropes, and that higher lags of accommodation are associated with faster myopia progression support this.[50,55,57,90] However, most studies concede that high accommodative lag is more likely to represent a consequence, rather than a stimulus for myopia,[91–93] and the relatively thinner anterior muscle in myopes has been suggested to be indicative that the increase in myopic ciliary muscle length may occur as a result of the muscle mass relocating to a more posterior position due to axial elongation, rather than the ciliary muscle undergoing related growth-related hypertrophy.[81]

Crystalline Lens

Structural changes in the crystalline lens are central to myopia development. Crystalline lens power reduces markedly during infancy,[94] with substantial inhibition of lens thinning and flattening evident 1 year before or within a year of myopia onset in children.[95] This phenomenon is concomitant with a reduction in both the refractive index and the dioptric power of the crystalline lens.[95] These findings support the notion that early onset myopia results from a breakdown in the independent relationship between lens changes and axial elongation.[95] Interestingly, it has been shown that there is a tendency for the crystalline lens to be thinner in myopic eyes than emmetropic eyes,[37–39] despite the apparent breakdown in co-ordination between lens thinning and axial growth. However, due to difficulties obtaining in vivo data of the crystalline lens' parameters as it accommodates, little is known about whether there are relevant functional implications of crystalline lens size or anatomic features, such as refractive index and rigidity, and whether these parameters differ between refractive groups.

Changes in the Posterior Segment in Relation to Accommodation and Myopia

Ostensibly, performance variation in the accommodative apparatus represents the most obvious anatomic candidate capable of precipitating myopia; yet, structural changes within the posterior segment during accommodation are emerging as being more likely to promote a myopic shift in susceptible eyes.

Various experimental paradigms using partial coherence interferometry[96–98] and optical low coherence reflectometry[99–102] have shown that the eye experiences a transient period of axial elongation after brief periods of sustained accommodation, both on axis[96–100,102] and in the periphery,[101] with the magnitude of change increasing with larger accommodative demand.[99] The exact mechanics by which the accommodative process instigates this phenomenon remains unclear; however, it is a long-held belief that the accommodating ciliary muscle applies an internal mechanical force upon the globe.[87,103] One such proposal is that posterior pole elongation occurs to maintain ocular volume despite the decreases in scleral and choroidal equatorial circumference, which arises owing to the increasing force exerted on the equatorial choroid by the contraction of the ciliary smooth muscle.[96,97] Although data to explicitly evidence a mechanical force model are scarce, Croft and colleagues[104] have reported centripetal movement of both the equatorial choroid and retina in rhesus monkeys during Edinger-Westphal stimulated accommodation, seemingly fitting this hypothesis.

The discovery of accommodation driven fluctuations in ocular length has given rise to the hypothesis that eyes which experience a greater magnitude of transient axial elongation may be more susceptible to permanent myopic shift.[97] Indeed, this notion seemingly dovetails with the suspicion that ocular rigidity differences may make an axially myopic eye more pliant to transient elongation.[97] There is now considerable evidence that myopic eyes demonstrate reduced posterior choroidal,[105] scleral,[106–109] and overall equatorial ocular wall[41,110] thickness compared with emmetropic eyes. Nonetheless, it remains unclear whether an association exists between in vivo anterior ocular rigidity and myopia susceptibility or progression,[41,42,111] particularly in light of the data derived from differential Schiotz tonometry, which suggests emmetropic and myopic adults[112] and children[41] have similar ocular rigidity and ocular wall stress.

To date, research comparing the magnitude of accommodation-induced transient axial elongation between emmetropic and myopic adults has produced contradictory findings, although it must be noted that studies have varied in design, type of accommodative stimulus, age range of participants, and refractive error. Mallen and colleagues[97] reported the largest disparity with a mean elongation of 0.037 mm in emmetropes versus 0.058 mm in myopes for a 6.0 D accommodative stimulus. Although it has since been suggested that these values present an overestimation due to artefactual instrument optical path length errors,[113] corrected values of 0.026 and 0.047 mm, respectively, are still in excess of those found by other studies.[101] Other researchers have reported either no significant group difference,[99,100,102] increased elongation in emmetropes,[96] or only a very small, but significantly greater, transient axial elongation in myopes.[99]

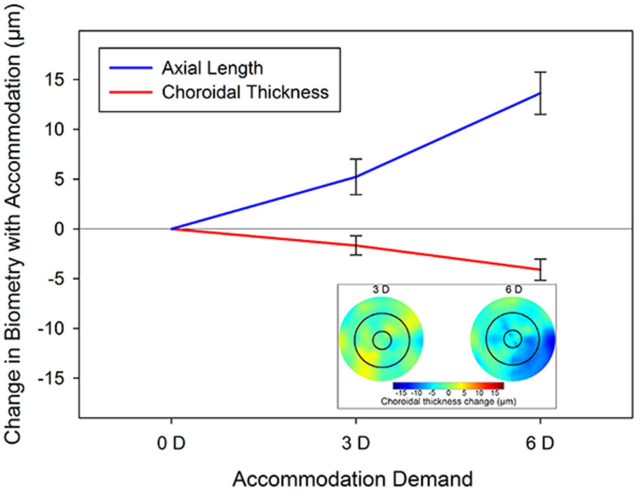

Figure 2. The changes in axial length (*top, blue line*) and choroidal thickness (*bottom, red line*) occurring during a short duration 3.0 D and 6.0 D accommodation task. Note the significant eye elongation and choroidal thinning that occurs at the higher accommodation demand. Inset illustrates the topographical choroidal thickness changes in the macular region occurring with 3.0 D and 6.0 D of accommodation (note that cool colors indicate a choroidal thinning with accommodation). From Woodman-Pieterse et al.[115]

Nonetheless, data suggesting no differences in the physical extent of relative elongation with ametropia do not necessarily rule out a potential role for transient axial elongation in accommodation-related myopia genesis,[99] as this does not account for variations in duration or intensity of nearwork activities[114] or other related features, which may even be responsible in isolation. All aforementioned studies are limited to providing a snapshot of biometric change during relatively short-duration accommodation tasks. The influence of longer periods of accommodation on transient axial elongation, and its ability and time period of recovery from these findings remain unknown.[99]

Although the mechanical model for transient axial elongation involves the choroid in an intermediary force transmission role, recent data indicate that its contribution may be substantially greater.[40] Certainly, in spatial terms, choroidal thinning during accommodation accounts for a significant degree of total elongation.[100,115,116] Woodman et al.[100] examined the subfoveal choroidal thickness change during a sustained 4.0 D accommodation task and reported a −8 µm choroidal thinning and approximately 20 µm axial elongation in a cohort of myopic and emmetropic participants. Subsequent OCT studies with higher accommodative stimuli have produced consistent findings,[115,116] and uncovered regional variations, with choroidal thinning being most prominent in temporal, inferior, and infero-temporal parafoveal zones (Fig. 2).[115] Choroidal thinning under transient axial elongation is likely to represent an element of feedback response of the choroid resulting from the accommodation, rather than purely a mechanical consequence of ciliary muscle contraction. The potential role of the choroid in the regulation of eye growth is currently under much scrutiny as changes in choroidal thickness are known to accompany eye growth, be more marked in highly myopic eyes and be bidirectional, with myopigenic factors leading to choroidal thinning and myopia-protective factors leading to causing choroidal expansion.[40] In the case of accommodation, choroidal thinning may be a compensatory mechanism to maintain a stable, optimally focused retinal image.[40,117]

How differences in choroidal thickness during accommodation may contribute to myopia development in the longer term is undetermined, and more work is needed to elucidate variations in response and recovery in myopes and emmetropes. Similarly, how changes in choroidal dynamics and position interact with other optical features of the myopic or pre-myopic eye, such as increased negative spherical aberration or accommodative lag, cannot be discounted as contributing factors to the development of myopia.[40]

Anterior Sclera

The semirigid scleral cup is the principal determinant of eye size and shape. During the development of myopia, the sclera undergoes a long-term, permanent remodeling process, whereby the structural and biomechanical properties of the sclera alter, making the globe more susceptible to expansion.[106,118] Changes in eye shape occur globally in all three dimensions (horizontal, vertical, and axial), although the magnitude of changes may vary with dimensions. It has been shown in humans that, compared with the emmetropic eyes, the eyes with myopia are elongated in both equatorial and axial dimensions, although the globe is elongated more in the axial dimension, resulting in a more prolate shape of the eye.[119] Significant negative correlations have also been reported between anterior scleral thickness near the scleral spur and increasing levels of myopia and axial length,[120] consistent with the negative correlation between posterior sclera thickness and axial length.[121] The scleral changes in myopia may thus occur well beyond the posterior pole and extend to the equatorial region or beyond.

The time courses of the accommodative system and scleral modeling vary substantially: accommodation has a much more rapid time course compared with scleral biomechanical changes in myopia.[122] The close juxtaposition of the accommodation apparatus, including the ciliary body, with the anterior sclera makes it plausible that accommodation could affect the anterior scleral properties. Recent studies have provided some evidence that the scleral shape undergoes short-term changes with accommodation. Woodman-Pieterse et al. measured changes in the anterior temporal sclera (1, 2, and 3 mm posterior to the scleral spur) in adult myopes and emmetropes using high-resolution anterior OCT, whereas the subjects fixated monocularly at near accommodative stimuli of 0.0, 3.0, and 6.0 D through a custom-mounted Badal optometer.[123] It was shown that the 6.0 D accommodative stimulus induced significant thinning of the anterior sclera, with more prominent changes in the myopic eyes at 3 mm posterior to the scleral spur for both accommodative stimuli. Niyazmand et al. reported changes in the shape of the anterior sclera in the horizontal meridian using eye surface profilometry in myopic and emmetropic young adults under conditions of 5.0 D accommodative demand, 9 degrees simulated convergence demand, and their combination.[124] Although changes were primarily evident at the naso-scleral region, all three conditions produced a significant reduction in the sagittal height of the anterior sclera (i.e. a reduction in elevation of the anterior sclera), whereas accommodation also produced a significant flattening of the anterior eye surface, but only when coupled with simulated convergence. These findings suggest that the anterior sclera perhaps thins and moves forward in response to accommodation. However, the reported changes could be due to convergent eye movement associated with accommodation or medial rectus contraction rather than an optically driven scleral response.[125]

MECHANISMS OF HOW ACCOMMODATION INTERRUPTS EMMETROPIZATION IN HUMANS

Whereas emmetropization is the long-term response of the eye in reducing or eliminating the defocus perceived at the fovea, accommodation is the immediate response of the eye to eliminate or reduce the hyperopic defocus presented during near work. The accuracy of accommodation has long been linked to the accuracy of refractive error development. Larger lags associated with high accommodative demand produce hyperopic defocus at the fovea providing a stimulus for the eye to grow longer and become myopic.[52,126] Previous studies have shown that myopic children accommodate less than emmetropic children.[50,57,91,127–130] The higher lags are shown to persist in some studies even when a near addition is given to the myopic children, as they use the add power and underaccommodate.[131] Several mechanisms have been proposed for how accommodation could cause myopia development in humans.

Accommodative Lag and Foveal Vision

Axial form deprivation due to the diffuse blur from high levels of accommodative lag and hyperopic defocus in the central retina could lead to the development or progression of myopia, as evidenced in animal experiments.[52,132,133] To date, longitudinal studies comparing the magnitude of initial accommodative lag with subsequent myopia progression have come to conflicting conclusions.[59,134] Accommodative lags of over 1.0 D are common during near vision in both emmetropes and myopes. These errors in accommodation are summarized for children in Table 1 and for young adults in Table 2. A lag of accommodation does not necessarily mean that the visual quality is poor during near vision. The need for accommodation will dependent on the range of clear focus which is influenced by monofocal and chromatic aberrations, pupil size,[135] and neural factors.[136] For a constant pupil diameter, differences in ocular aberrations between myopes and emmetropes are observed and are variable in both accommodative and nonaccommodative states.[137,138] Attempts to slow myopia progression using interventions targeted at improving accommodative lag, such as progressive lens wear groups (PALs) have been largely unsuccessful, even when including children with high lags of accommodation and near esophoria.[139–141] Cheng et al.[141] additionally used base in prism along with progressive addition lenses to offset the positive-lens-induced exophoria and found no difference in myopia control efficacy in children with high lags of accommodation, however, the small gain in efficacy may be related to

Table 1. Effect of Refractive Error and Measurement Methods on Accommodation Errors at Near Vision in Children

Paper	Measurement Method	Accommodation Stimuli	Mode of Myopic Correction	Age, y	Refractive Groups	AE, D	Summary of Results
Rouse et al. (1984)[128]	MEM dynamic retinoscopy	Monocular FV usual near demand	Habitual spectacle correction	5–11	Not specified	−0.30	Relationship between age and lag
Gwiazda et al. (1993)[50]	Canon R–1 Autoref	Monocular FV/NL/PL 0–4 D demand	Soft contact lenses	5–17	EMMs MYPs EMMs MYPs	−0.30 FV −0.66 FV −0.56 NL −1.61 NL	MYPs had greater lags than EMMs. Lags were greater for NL
Chen and O'Leary (2002)[287]	Canon R–1 Autoref	Monocular FV/NL 0–4 D demand	N/A	3–14	EMMs	−0.29 FV −0.69 NL	Lags greater for NL
McClelland et al. (2004)[127]	Nott Dynamic Retinoscopy	Monocular FV 4–10 D demand	Habitual correction	4–15	Not specified	−0.30 at 4 D −2.50 at 10 D	Lags increased as the demand increased
Mutti et al. (2006)[91]	Grand Seiko WR5001K or Canon R–1 Autoref	BLV/FV 2 D and 4 D demand	Habitual spectacle correction	6–15	EMMs EMMs MYPs MYPs	−1.00 FV −0.91 BLV −1.12 FV −1.40 BLV	Increased lags found in MYPs after they became myopic but not in EMMs who became MYPs
Langaas et al. (2008)[143]	Plus Optix Power Refractor 11	Binocular FV 0.25–4 D demand	Spectacle correction	Ave 13 14	EMMs EOMs	−0.10 –0.10	Lags were greater at the 2 D than the 4 D viewing condition
Weizhong et al. (2008)[134]	Shin-Nippon Autoref	Monocular FV 3 D demand	Spectacle correction	Ave 11	EOMs	−0.76	No relationship between accommodation lag and myopia progression over 1 y
COMET 2 (2011)[140]	Grand Seiko WR5001K	Monocular FV 3 D demand	Spectacle correction	8–12	MYPs SVL MYPs PAL	−1.40 −1.47	Both myopic groups of children exhibited larger accommodative lags. The treatment effect of the PALs was greater in children with lags greater than −1.5 D.
Berntsen et al. (2011)[139]	Grand Seiko WR5001K or Canon R–1 Autoref	BLV/FV 4 D demand	Spectacle correction	6–14	MYPs SVL	−1.59	Myopic children had high lags of accommodation, but the magnitude of the lag was not related to the annual myopia progression
Yeo et al. (2013)[218]	Shin-Nippon Autoref	Binocular FV 3 and 4 D demand	Spectacle correction	7–12	EMMs MYPs	−0.96 −1.01	Chinese children had high lags of accommodation when reading either English or Chinese texts
Han et al. (2018)[288]	Fused cross cyl	Binocular, Phoropter 4 D demand	Spectacle correction	9–14	MYPs SVL	−1.0	Orthokeratology and concentric progressive lenses reduced the lag of accommodation
Ma et al. (2019)[289]	Shin-Nippon Autoref	Monocular FV 3 D demand	Spectacle correction	8–12	MYPs SVL	−1.0	Myopic children with high lags showed reduction in lag both with in office placebo therapy and accommodation vergence training
Chen et al. (2019)[130]	Grand Seiko WR5001K	Monocular FV 4 D demand	Spectacle correction	8–12	EMMs MYPs SVL	−0.20 −0.65	Myopic children had greater lags. Lags increased in mesopic lighting conditions

AE, accommodative error at highest demand conditions; BLV, Badal lens viewing; EMMs, emmetropes; EOMs, early onset myopes; FV, free viewing; HS, Hartmann Shack; lag, accommodation lag; MYPs, myopes; N/A, not applicable; NL, negative lens series; PAL, progressive lens wear group; PL, positive lens series; SVL, single vision lens wear group; VA, visual acuity.

Table 2. Effect of Refractive Error and Measurement Methods on Accommodation Errors at Near Work in Young Adults

Paper	Measurement Method	Accommodation Stimuli	Mode of Myopic Correction	Age, y	Refractive Groups	AE (D)	AEI	ASRC	Summary of Results
McBrien and Millodot, (1986)[49]	Canon R-1 Autoref	Binocular free viewing (FV) 0–5 D demand	Soft contact lenses	18–23	EMMs	−0.54			EOMs and LOMs had greater lags than EMMs
					EOMs	−0.69			
					LOMs	−0.83			
Bullimore et al. (1992)[290]	Canon R-1 Autoref	Monocular FV/NL/PL 1–5 D demand	Soft contact lenses	19–23	EMMs	−0.60			LOMs had greater lags for passive tasks at high demands
					LOMs	−0.73			
Abbott et al. (1998)[57]	Canon R–1 Autoref	Monocular FV/NL/PL 0–4 D demand	Soft contact lenses	18–31	EMMs	0.01 NL			Progressing MYPs had greater lags for NL conditions only
					SMs PMs	0.01 NL −0.52 NL			
Jiang and Morse (1999)[291]	Canon R-1 Autoref	Monocular Badal lens viewing BLV up to 5 D demand	Soft contact lenses or spectacles	20–30	EMMs			0.74	All 3 refractive groups had similar lags
					SMs			0.77	
					PMs			0.67	
Rosenfield et al. (2002)[292]	Canon R–1 Autoref	Binocular FV 0–5 D demand	Soft contact lenses	21–27	EMMs	−0.34 FV		0.99	Greater lags found in stable MYPs than initial EMMs and MYPs that progressed over a 1 y period
					SMs	−0.34 FV		0.96	
					PMs	−0.20 FV			
Subbaram and Bullimore (2002)[65]	Canon R–1 Autoref	Monocular BLV 0–4 D demand	Spectacles	20–30	EMMs	−0.29			Small lags found in both refractive groups
					PMs	−0.29			
Seidel et al. (2003)[293]	Canon R-1 Autoref	Monocular BLV 0–4.5 D demand	Soft contact lenses	17–26	EMMs			0.81	All 3 groups had similar lags but greater response variability in the myopic groups
					LOMs			0.81	
					EOMs			0.80	
Hazel et al. (2003)[294]	Shin-Nippon Autoref SRW 5000 Wavefront Sensor (HS)	Monocular NL 0–4 D demand	Soft contact lenses	18–27	EMMs	−0.72			Lags greater when measured with the autorefractor when adjusted for similar pupil size

Table 2. Continued

Paper	Measurement Method	Accommodation Stimuli	Mode of Myopic Correction	Age, y	Refractive Groups	AE (D)	AEI	ASRC	Summary of Results
					MYPs	−1.01			
					EMMs	−0.50 HS			
					MYPs	−0.43 HS			
Nakatsuka et al. (2003)[54]	Open field autorefractor	Monocular FV 2-6.25 D demand	Habitual spectacle correction	19–38	EMMs			1.02	Good accommodative accuracy in both refractive groups
					EOMs			1.05	
Schmid et al. (2005)[295]	Shin-Nippon Autoref SRW 5000	Monocular BLV 4 D demand	Soft contact lenses	18–25	EMMs	0.29			EMMs and MYPs had similar lags, response more accurate for smaller targets at the same distance
					MYPs	0.33			
Day et al. (2006)[296]	Shin-Nippon Autoref SRW 5000	Monocular BLV 0–4 D demand	Soft contact lenses	Ave 22	EMMs		0.73		EMMs and LOMs had greater lags than the EOMs
				Ave 22	EOMs		0.86		
				Ave 28	LOMs		0.70		
Allen and O'Leary (2006)[59]	Power refractor	Monocular and Binocular FV 3 D demand	Habitual correction	18–25	EMMs		0.35		Increased binocular lags with increasing degree of myopia
					EOMs		0.41		
					LOMs				
Harb et al. (2006)[162]	Power refractor	FV 3.5 D demand	Soft contact lenses	22–28	EMMs	−0.99			Myopes had greater variability in their accommodation response and had larger lags at greater reading distances
					MYPs	−0.99			
Sreenivasan et al. (2013)[297]	COAS Aberrometer	Monocular plus 3 Binocular tasks 1-5 D demand	Spectacle correction equivalent	18–25	EMMs	−0.70			MYPs showed greater lags but had better near VA than EMMs
					MYPs	−1.20			

AE, accommodative error at highest demand conditions; AEI, accommodation error index; ASRC, slope of the accommodation stimulus response curve; BLV, Badal Lens Viewing; EMMs, emmetropes; EOMs, early onset myopes; FV, free viewing; HS, Hartmann Shack; lag, accommodation lag; LOMs, late onset myopes; MYPs, myopes; NL, negative lens series; PAL, progressive lens wear group; PL, positive lens series; PMs, progressing myopes; SMs, stable myopes; SVL, single vision lens wear group; VA, visual acuity.

improved accommodation-convergence balance. The accommodative lag hypothesis in myopia thus remains contentious and warrants further investigation.

Accommodative Instability

Besides inaccuracies in accommodation, it seems that accommodative instability (as assessed by objective dynamic accommodation recordings to different dioptric targets) may be important in myopia development as both children[142,143] and adults[144] with myopes showing less stable accommodation responses. Unstable accommodation responses would prevent the formation of a steady clear retinal image, with possible consequences for myopia development and progression.

Near Induced Transient Myopia

Another important characteristic of the accommodation response is that, after prolonged exposure to a near stimulus, there is normally a delay in accommodation relaxation when the person looks far away, termed "near work induced transient myopia." Retinal defocus induced by near work induced transient myopia is larger and persists for longer in late-onset[145] and progressing[146,147] adult myopes and children in whom it lasts longer,[148] indicating a possible contributing factor to permanent myopia.[149] Interestingly, near work induced transient myopia is also increased in the more myopic eye compared with the fellow less myopic eye of anisomyopes.[150]

Near-Peripheral Vision and Accommodation

Relative peripheral refraction, measured as the difference between foveal and peripheral refractive error, is known to have a significant influence on myopia development and control.[151,152] Myopes tend to have hyperopic relative peripheral refraction ,whereas hyperopes have a myopic relative peripheral refraction.[132,152] Changes in the shape of the eye with accommodation and accommodative lag could further influence the peripheral refractive error and also aberration changes with accommodation may effect off-axis refractive errors during accommodation. Myopes are likely to have larger ciliary muscle mass,[78,153–155] therefore accommodation could lead to an expansion in the dimensions of the myopic eye due to the force created by the larger ciliary muscle. This would lead to changes in relative peripheral refraction in myopes. As previously discussed, evidence on clinically significant changes in axial length and central refractive error with near work is equivocal.[156–158] Discrepancies in these studies can be attributed to the level of myopia in the participants and the techniques used, with significant differences in high myopes. Accommodation has been shown to induce the ocular shape to become more prolate.[159] The changes in relative peripheral refraction with accommodation are modest and are relatively similar in myopes and emmetropes.[157,160,161] Yet, the larger accommodative lags present during near work (which might be higher in myopic children due to the close working distances adopted) would increase the peripheral hyperopic defocus further in myopic eyes.[162]

Sensitivity to defocus in the peripheral retina is expected to be lower than the central retinal sensitivity. Cone and ganglion cell density and visual quality decreases with field angle, so peripheral visual resolution is low and has lower sensitivity to defocus. The depth of focus at a peripheral field of up to 45 degrees remains around ±1 D[163]; therefore, any changes in the peripheral focus of over ±1 D are likely to be perceived as defocussed in the peripheral retina and could disrupt the emmetropization process. Postural control is a requisite in maintaining a stable body and to ensure safety and prevent injuries and the visual system contributes significantly to postural stability.[164,165] Myopes show a higher postural instability to peripheral stimuli and distortions presented in the stimuli than emmetropes, further indicating that the peripheral vision in myopes is likely to be more sensitive than in emmetropes.[166] It has been shown that myopes display an asymmetry to defocus being less sensitive to negative defocus (hyperopic) than positive (myopic) defocus in both peripheral and central vision compared with a more symmetrical response in emmetropes.[167–169] It has also been suggested that the eye derives the odd error cues for the direction of defocus using the oblique astigmatic foci (difference between radial and tangential foci) in the peripheral vision.[135]

Stimuli falling on the peripheral retina can elicit an accommodative response.[170–172] However, the accuracy of accommodative response progressively reduces with retinal eccentricity. Hartwig et al.[172] found that relative to accommodative stimulus-response slope to central targets, the rate of reduction in slope with peripheral accommodative stimuli was lower in myopes when compared with emmetropes. This finding supports previous studies that indicate that the peripheral retina in myopes is more sensitive to hyperopic defocus than emmetropes up to field angles of at least 15 degrees. Although these studies show that the peripheral retina can alter the accommodation response of the eye, the exact nature of the response and how this might summate with the stimuli falling on different regions of the retina is still unclear.

Sensitivity to Blur: Detection and Discrimination Thresholds

Blur sensitivity is decreased in adults with myopia,[173,174] and the detrimental effect of central attention in peripheral vision is also larger in myopia.[175] Schmidt et al.[176] measured children's ability to detect blur and found no differences among refractive groups, but they did not evaluate blur discrimination. More recently, Labhishetty et al.[177] showed that even though children with progressive myopia show increased depth of focus, they do not show increased blur detection thresholds. The effect of blur adaptation[178,179] on blur sensitivity is also larger in early onset myopes compared to emmetropes,[180] although this effect may only occur with isolated letters,[181] perhaps due to lateral masking, and it is dependent on the lateral extent of the stimulus.[182] These findings suggest that the reduced sensitivity to defocus in myopia may be compensated with higher level adaptation processes to preserve the subjective clarity even in the presence of decreased retinal image quality.[177] One limitation is the lack of consideration of whether myopes regularly wore their full correction, thus potentially impacting on adaption.

Current models of refractive error development agree on the importance of image quality across the retina to guide emmetropization, not only at the fovea.[183–187] It appears that a balance across the retina is critical for normal emmetropization; peripheral blur, with or without clear central vision, may induce myopia.[184–188] Retinal defocus is known to decrease peripheral sensitivity, particularly to low light level stimuli.[189] The human decoding system for blur is tuned for low and mid-spatial frequencies and appears to be located in the retinal near periphery (up to 15 degrees).[182,190,191] Accommodation can also be elicited by near peripheral defocus,[192,193] and myopes may demonstrate less effective peripheral accommodation.[194]

Greater losses of peripheral function have been noted in myopes than emmetropes,[195–197] probably due to retinal expansion.[198] Myopes also show a greater degree of adaptation to peripheral blur,[199] and, unlike emmetropes, myopes do not show a constant pattern of peripheral defocus during accommodation.[192] Differences in sensitivity to myopic and hyperopic defocus in the periphery are only seen in myopes, indicating different effects of radial and tangential blur during emmetropization.[200]

Spatial Frequency and Contrast Cues in Accommodation

Reading often requires viewing high-contrast text at close distances for prolonged periods. Spatial frequency and contrast of reading text are often limited in range when compared to natural scenes, which can lead to further spatial and contrast adaptation.[122] Myopes show a reduced sensitivity to defocus blur when compared with non-myopes.[168,169,201,202] The reduction in blur sensitivity diminishes the effect of accommodative lag on visual performance and increases blur and contrast adaptation in uncorrected myopes.[203] Contrast adaptation leads to a decrease in contrast sensitivity at a specific spatial frequency after viewing high-contrast targets of a similar spatial frequency.[204] The adaptation effect increases with time and a longer adaptation period requires a longer recovery period.[205,206] A degraded retinal image as a consequence of contrast adaptation may lead to perceptual blur, which in turn could result in myopia development.[207] During reading tasks, contrast adaptation is expected to reduce contrast sensitivity to spatial frequencies similar to the row or stroke frequency of the text.[208] Studies on myopic children and adults have shown that myopes demonstrate a significantly higher level of contrast adaptation (nearly 2 times) in comparison to emmetropes.[208,209] The contrast adaption was shown at different spatial frequencies in these two studies owing to differences in targets used (paper versus cathode ray tube display) and age of the participants (children versus adults). Nonetheless, the higher contrast adaptation levels, as seen in myopes, are expected to degrade retinal image significantly more in myopes during prolonged near tasks, therefore, possibly contributing to myopia development/progression. However, it is unclear whether these differences in contrast adaptation are a precursor or consequence of myopia.

Contrast adaptation has been shown to occur when the eye is exposed to positive (myopic) defocus but not to negative (hyperopic) defocus, however, the reason for this is currently unknown.[210] In addition, McGonigle et al.[208] found that myopes show higher levels of contrast adaptation after reading text on a cathode ray tube when compared to emmetropes, despite ensuring that there was no accommodative lag present in either group. The contrast adaptation differences between myopes and emmetropes are, therefore, unlikely to be caused due to larger lags seen in myopes when reading.[91,211]

In regions where the prevalence of myopia is high, children and adults read both Chinese and English. Chinese characters have a relatively greater content of high spatial frequency components compared to Latin characters.[212] Accommodation to low spatial frequencies (1 c/deg or less) tends to produce higher lags; the optimal accommodative response is produced for spatial frequencies at the peak of photopic contrast sensitivity (3–5 c/deg).[213–215] No systematic differences have been found in accommodative responses of emmetropes and myopes to sinusoidal grating targets of different spatial frequencies,[216] nor to Chinese and Latin characters.[217,218] Contrast adaptation too was similar for Chinese and Latin text, although it was found to be higher in myopes.[209]

INTERACTIONS OF MONOCHROMATIC ABERRATIONS AND ACCOMMODATION

Higher-order aberrations affect the visual quality of the eye and provide odd-error signals, which can help the eye detect the direction of defocus thereby contributing to the regulation of accommodation and refractive error development. Spherical aberration can provide odd-error cues to identify the sign of defocus in the central visual field, whereas coma and astigmatism can provide the cues for direction of defocus in the peripheral visual field.[135,219,220] Higher-order aberrations alter in a similar way to spherical and cylindrical refractive errors during emmetropization.[221] The intersubject variability in higher-order aberrations is high and this may be why studies looking at differences in aberrations between myopes and emmetropes have reported inconclusive results, both in cross-sectional and longitudinal studies.[137,138,222] The interaction between individual higher order aberrations, such as spherical aberration and defocus, is more likely to affect the visual quality and refractive development rather than the absolute magnitude of individual aberrations or the total root mean square error of higher-order aberrations. Higher order aberrations change with accommodation; spherical aberration has been consistently shown to have a negative shift with accommodation in young individuals with a greater change in myopes.[138,223] Negative spherical aberration can improve image quality when it interacts with myopic defocus and can degrade image quality when combined with hyperopic defocus as produced by accommodative lag.[220] It is therefore hypothesized that the higher accommodative lags during extended periods of near work in myopes, when combined with the negative spherical aberration produced during accommodation, would interact and degrade retinal image quality further in myopes more than that in emmetropes who experience lower lags during near work.

Color Based Cues

Longitudinal chromatic aberration can extend the best focus of the eye by approximately 2.0 D and, hence, can also provide the odd error cue for accommodation and emmetropization (Fig. 3). Accommodative response in humans also varies with wavelength, with the eye accommodating more for longer wavelength and showing an approximately 1.0 D difference in response across the visible spectrum.[224] The difference in contrast produced due to longitudinal chromatic aberration between long and short-wavelength light can also help detect the direction

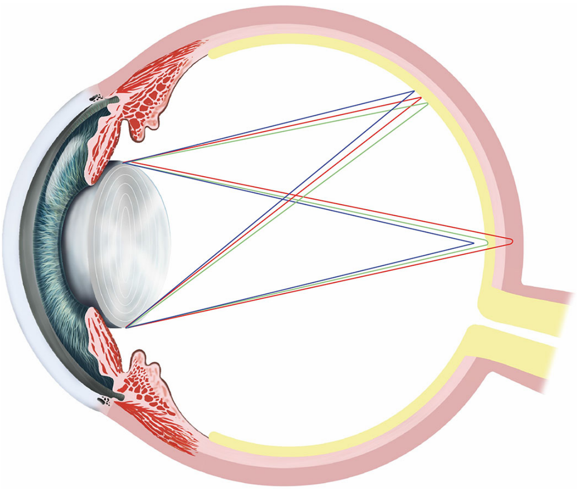

FIGURE 3. The visual stimulus from chromatic aberration in longitudinal (along the optic axis) and transverse (affecting the peripheral retinal image) planes. Copyright © 2021 by IMI.

of defocus.[225] Although the eye can accommodate and emmetropize in the absence of chromatic cues, as shown by the monochromatic light studies in animals, the presence of chromatic signals seems to increase the response accuracy of both emmetropization and accommodation systems.[226] It has been hypothesized that the myopic eye emmetropizes to reach optimal focus using either the red/green color sensitive mechanism or the luminance sensitive mechanism, relative to the optimal focus for the blue/yellow color, which is more myopically defocused.[227] This hypothesis is supported by the fact that myopes show increased sensitivity to long wavelength cone contrast and reduced sensitivity to short wavelength cone contrast when compared to emmetropes.[228] However, how this translates to a mechanism for myopia development is unclear.

NEAR WORK POSTURE

Near working distances tend to be between 10 and 40 cms in 6 to 11-year-old children and children with habitually short reading distances are likely to have higher magnitudes of myopia.[4,229–231] The relatively short near working distances in addition to the asymmetric head posture, as adopted by most children, can lead to differences in accommodative demands between the two eyes. As the reading distance is reduced, the intraocular difference in accommodative demand increases with all spatially extended tasks.[232] As the working distance gets closer, the head tilt increases.[129,233] With a head tilt, one eye would consistently encounter higher time-averaged accommodative demand than the other eye leading to aniso-accommodative demand. As accommodation is a binocular process, aniso-accommodation is likely to be rather small (0.25 D or less) between the two eyes.[234,235] Therefore, substantial levels of blur can be perceived by the eye when the aniso-accommodative demand is coupled with high accommodative lags. Further, this nonuniform distribution of dioptric stimuli during near work could also exacerbate the effect of defocus in peripheral vision, particularly so when head tilts occur.

Working distance, head posture, and eye movements have been shown to be similar in adult myopes and emmetropes over relatively short periods of reading tasks.[236–238] However, myopic Chinese children have been shown to have significantly closer working distances during near tasks, which tend to be closest with video game tasks on hand held devices.[233] Working distance also reduces with increased attention and concentration.[231] This could reduce the working distance with hand held devices when compared to previous studies conducted with paper based reading tasks. The closer working distances would lead to yet higher accommodative lags, further degrading vision particularly at higher spatial frequencies.

DIFFERENCES IN INDOOR AND OUTDOOR ENVIRONMENTS AS RELATED TO ACCOMMODATION

It is well established that spending more time outdoors prevents myopia development and progression.[239–257] One significant difference of outdoor versus indoor environments is the level and uniformity of dioptric blur across the retina[190]; objects are typically further away so there is less dioptric variation across the visual scenes in outdoor environments and pupil miosis is greater due to higher illumination levels leading to a greater depth of focus, therefore, less accommodative response is demanded.

Binocular Vision

Binocularity is important in the formation of the retinal image. Binocularity improves the accommodative response to defocus,[258] and, in turn, blur due to defocus is a useful cue in binocularity.[259,260] This effect may be different in myopes.[261] Although emmetropization signals are found locally at the retinal level, binocular vision may play a significant role in retinal image focus and therefore in emmetropization and potentially for myopia development. Blur sensitivity, for example, is reduced in myopes under monocular but not binocular conditions.[173] Myopes also show reduced stereopsis with flickering stimuli and greater binocular imbalance compared with emmetropes.[262] Night myopia, or tonic accommodation, is reduced under binocular conditions[263] and the accommodative gain is different with a translucent occluder over the nonviewing eye than binocularly in emmetropes but not in myopes.[264]

One method to clinically measure disturbances of binocular vision is the magnitude of the accommodative-convergence to accommodation (AC/A) ratio. Higher AC/A ratios have been documented in myopic children compared to emmetropic children.[265] Studies have found the AC/A ratio to be elevated prior to myopia onset[126] and as early as 4 years prior to myopia onset.[266] The AC/A ratio has been found to reach its peak at myopia onset and remain both stable and raised through at least 5 years after myopia onset. The increased AC/A ratio in myopic children could result from a higher gain of the cross-link from accommodation to convergence, or it could represent an increased effort required per diopter of accommodative output, even if the accommodative convergence cross-link gain relationship may be relatively constant. Mutti and colleagues found a higher AC/A ratio correlated with a greater lag of accommodation, but was not associated with a faster rate of myopia progression.[266] This effect may be related to the observed changes in the ciliary muscle between myopes and emmetropes.[78,153] The effect of refractive error on phoria and AC/A is summarized in Table 3.

Table 3. Effect of Refractive Error on Phoria and AC/A in Children and Young Adults

Paper	Measurement Method	Mode of Myopic Correction	Age, y	Refractive Groups	Near Phoria (Δ)	Response AC/A (Δ/D)	Summary of Results
Rosenfield and Gilmartin (1987)[298]	IR Autoref and Maddox rod	Trial frame and lenses	18-27	EMMs		3.0	Higher AC/A ratios in LOMs than EOMs than EMMs
				EOMs		3.9	
				LOMs		4.6	
Goss (1991)[299]	Canon R-1 Autoref von Graefe phoria	Trial frame and lenses	6-15	EMMs	−2 exo		Onset of myopia preceded by vergence changes
				Became MYPs	+1 eso		
Jiang (1995)[300]	Canon R-1 Autoref Phoria method not mentioned	Trial frame and lenses	18-27	EMMs		0.9	Higher AC/A ratios in EMMs that became Myopes
				Became MYPs		1.4	
Gwiazda et al. (1999)[301]	Canon R-1 Autoref with attached motorized Risley prism and Maddox rod	Trial frame and lenses	6-14	EMMs		3.9	Higher AC/A ratios in myopic children
				MYPs		6.4	
Mutti et al. (2000)[265]	Simultaneous accommodation and vergence measures Canon R-1 Autoref Purkinje images I and IV	Habitual correction	6-14	EMMs		3.9	Higher AC/A ratios in myopic children
				MYPs		6.4	
Chen et al. (2003)[302]	Shin-Nippon Autoref with Howell Dwyer Card	Trial frame and lenses	8-12	EMMs	−0.7 exo	2	AC/A ratios and phoria were similar in EMMs and MYPs
				MYPs	−1.0 exo	3	
Gwiazda et al. (2005)[126]	Canon R-1 Autoref with attached motorized Risley prism and Maddox rod	Trial frame and lenses	6-18	EMMs	−2.9 exo	7.5	Elevated AC/A in EMMs who became myopic, 2 y prior to onset
				Became MYPs	−0.4 exo	>9	
Allen and O'Leary (2006)[59]	PowerRefractor with a Bernell Muscle Imbalance Measure (MIM) test card and Maddox rod	Trial frame and lenses	18-22	EMMs		3.5	Elevated AC/A not related to myopia progression
				EOMs		4.2	
				LOMs		3.6	
Price et al. (2013)[274]	Shin-Nippon Autoref with Howell Dwyer Card	Trial frame and lenses	14-21	MYPs		4	Elevated AC/A was related to myopia progression
Zadnik et al. (2015)[303]	Simultaneous accommodation and vergence Canon R-1 Autoref Purkinje images I and IV	Habitual correction	7-13	EMMs		4	High AC/A myopia risk factor
				Became MYPs		7	
Mutti et al. (2017)[266]	Simultaneous accommodation and vergence Canon R-1 Autoref Purkinje images I and IV	Habitual correction	6-14	EMMs		4	AC/A increased up to 4 y prior to myopia onset
				Became MYPs		7	

AC/A, accommodation convergence to accommodation response ratio; EMMs, emmetropes; EOMs, early onset myopes; LOMs, late onset myopes; MYPs, myopes.

Theoretically, a greater AC/A is also likely to shift the eyes toward esophoria at near work in these myopic children. Near positive (base in) fusional vergences are also higher in progressing myopes.[267] Interestingly, myopic children exhibit less convergent shifts in vergence adaptation compared to emmetropes, which could be attributed to higher accommodative adaptation (as assessed by changes in tonic accommodation).[268] When myopia is controlled with orthokeratology, the child's zone of clear single binocular vision becomes more divergent and the accommodation responses increase relative to that measured under correction with single vision spectacles.[269]

Accommodation With Optical Myopia Control Interventions

All contemporary optical interventions for myopia are based on a common premise that reducing off-axis hyperopic blur or inducing off-axis myopic blur should slow the progression of myopia.[152] Their optical designs incorporate one or more paracentral or peripheral zones of plus power around a central clear zone so as to induce areas of peripheral or simultaneous myopic blur in the retina while providing clear on-axis focus and vision through the center. Such dual power designs have the potential to interfere with the accommodative and binocular system, because myopic children may underaccommodate by looking through relative plus zones, further weakening the potentially diminished accommodative function due to myopia.

Several studies have investigated the effect of soft bifocal or multifocal contact lenses on accommodative response in adults, but the results are mixed. Some studies have shown either similar response to single vision contact lens wear[270] or a lead of accommodation,[271] others have shown increased accommodative lag,[272] reduced monocular accommodative facility,[273] and exophoric shifts at near.[272] It has also been shown that spherical aberration modifying lenses do not affect accommodative facility and horizontal phoria,[274] and adding negative aberration can improve the slope of the accommodation stimulus-response curve, reducing lag of accommodation.[275] Orthokeratology lens wear has also been shown to increase exophoria in young adult myopes.[269] However, unlike soft multifocal lenses, orthokeratology lenses have been found to lower accommodative lags at near, prompting some to suggest that these lenses may be a better strategy to slow reduce myopia progression in adults with binocular vision disorders.[276]

Studies in children show reduced accommodation response and an increase in exophoria while wearing center-distance soft bifocal[277] or multifocal contact lens[278] compared with single vision contact lenses, suggesting that perhaps children resort to using the relative plus power in an attempt to relax accommodation. However, in other studies, no difference in binocular or accommodative function can be detected in children wearing dual-focus contact lenses or extended depth of focus lenses, compared with single vision contact lenses[279–282] suggesting that they can accommodate normally using the distance portion of the lenses, but longer term monitoring is warranted.

TRANSLATION TO CLINICAL PRACTICE

Evidence from animal studies shows that exposure to hyperopic defocus results in a disruption to the normal emmetropization process and leads to the development of myopia.[132] Although the evidence in humans is less clear, chronic retinal defocus at near work, due to a lag in accommodative response, is more frequent and often greater in myopes. This blur at near work has been suggested to trigger a series of biochemical events, which could result in scleral remodeling and axial elongation in an attempt to improve image clarity.[132] Thus, addressing retinal blur arising from accommodation has been explored in human longitudinal studies, but results from these studies are mixed.[152,283,284]

A large-scale longitudinal cohort study has shown that an increased accommodative lag occurs in children after the onset of myopia.[91] Therefore, an elevated accommodative lag is unlikely to be a useful predictive factor for the onset of myopia. Lag of accommodation has not been found to be associated with myopia progression.[285] It is more probable that an increased hyperopic defocus from accommodative lag may be a consequence rather than a cause of myopia. Esophoria at near work has not been associated with myopia progression in studies using bifocal or progressive addition spectacle lenses (for review see Wildsoet et al.[152]) and may result as compensation for deficient accommodation rather than a causative factor for myopia progression.[286]

CONCLUDING REMARKS

It is evident that, to date, the role of accommodation and binocular vision in the development and progression of myopia is not fully understood. Aspects of blur from the lag of accommodation, the impact of spatial frequency at near work, and a short working distance may all be implicated in myopia development and progression. The response of the ciliary body and its links with changes in the choroid are still being explored with respect to myopia development and progression. Researchers have not ruled out the role of the accommodative system in this field, but current methods of intervention based on this theory have not yielded significant results. Based on the evidence to date, eye care practitioners should consider assessing the accommodation and convergence system in young myopes and those at risk of myopia development to ensure they manage their patients by providing a clear retinal image. Current evidence does not point toward a role for accommodation and binocular vision in myopia development and progression.

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