The Relationship Between Tonic Accommodation and Refractive Error

Neville A. McBrien and Michel Millodor

It is now well established that accommodation adopts an intermediate resting position in the absence of visual stimulation. It also has been shown that this tonic position of accommodation exhibits considerable variation among individuals (ie, 0–4 D). Previous studies have been somewhat inconclusive as to whether these individual differences in tonic accommodation are related to the refractive properties of the eye. This study investigates the relationship between tonic accommodation and refractive error with particular reference to both the value and the time course of tonic accommodation. Sixty-two subjects were used for the study, with an age range of 19–25 yr. Subjects were placed into one of four refractive groups, after considering factors pertaining to the theories of refractive development. Dark-room measures of tonic accommodation were determined using the infrared objective autorefractor, Canon Autoref R-l®. Significant differences were found among the four refractive groups, with corrected hyperopes having the highest dioptric value of tonic accommodation and corrected late-onset myopes having the lowest dioptric value. The significant difference found between early- and late-onset myopes is suggested as a possible reason for the inconclusive results of some previous studies. It also was found that the time taken to reach a stable tonic position of accommodation was much slower for the hyperopic group than for the other refractive groups. The results are discussed in the light of recent findings on accommodative hysteresis and with respect to a dual innervation to the ciliary muscle. Invest Ophthalmol Vis Sci 28:997-1004, 1987.

Accommodation is defined as the function whereby the refractive power of the optical system of an eye can change, so that images of both distant and near objects can be brought to a clear focus on the retina.

The classical theory of accommodation assumes that the only active process of accommodation is an increase in the refractive power of the eye, produced by contraction of the ciliary muscle. This theory proposes that only parasympathetic innervation to the ciliary muscle is important in active accommodation. When this parasympathetic system is activated, an increase in refractive power is produced; when innervation ceases, relaxation of the ciliary muscle occurs, and the refractive power of the eye is decreased. Hence, when the parasympathetic innervation is at a tonic level, the ciliary muscle is assumed to be relaxed and the eye is focused at its far point, which for an emmetropic eye would be at optical infinity.

Although this concept has been accepted widely since it was first proposed by Helmholtz, it has, in recent times, been shown to be inaccurate. Both pharmacologic and anatomic investigations have demonstrated the presence of a sympathetic innervation to primate and human ciliary muscle. This sympathetic innervation has been shown to be both β receptor mediated and inhibitory in nature.

It is now well established that the eye adopts an intermediate resting position in the absence of visual stimulation (ie, Leibowitz and Owens). Epstein has shown the primary cause of this so-called anomalous myopia to be accommodation. Because this myopic shift under dark-room conditions is a result of the equilibrium established between sympathetic and parasympathetic tone, the most appropriate term to describe the phenomenon is tonic accommodation. An interesting feature of the tonic position of accommodation is that it exhibits considerable variation between individuals, although the value for a given individual is remarkably stable over time. This large intersubject variation (ie, 0–4 D) has been the subject of investigation to determine whether the refractive properties of the eye are related to these individual differences in tonic accommodation. Studies on this relationship between tonic accommodation and corrected refractive state have shown no conclusive relationship; however, a tendency for a
higher tonic position of accommodation in hyperopia and lower in myopia has been found in some studies\(^{17,18,20}\). Possible factors contributing to the inconsistencies between studies are the different criteria used for refractive grouping, unequal numbers of subjects within groups, and the different measurement techniques employed.

Moreover, recent findings on other aspects of the accommodative response, namely amplitude of accommodation\(^{22,23}\) and the accommodative response gradient\(^{24}\) (i.e., the slope of the accommodative response curve) have shown significant differences with respect to refractive state. The purpose of the present investigation was to determine, under strictly controlled conditions, whether a relationship also exists between tonic accommodation and refractive error.

**Materials and Methods**

The subject population consisted of 62 Caucasian university students aged 19–25 yr, placed into one of four refractive groups, after considering factors pertaining to the theories of refractive development.\(^{25}\) The emmetropic group (\(n = 17\)) covered the refractive range \(-0.25\) D to +0.75 D best-sphere equivalent, based on the large-scale studies of the distribution of ocular refraction,\(^{26,27}\) which clearly show that, in Caucasians, approximately 70% of all eyes fall within this refractive range. The hyperopic group (\(n = 15\)) consisted of subjects whose ocular refraction was above +0.75 D best-sphere equivalent. The myopes accordingly were subjects whose myopia was greater than \(-0.25\) D best-sphere equivalent. The myopic subjects were further subdivided into two groups: (1) earlier-onset myopes (onset 13 yr or earlier, \(n = 15\)) and (2) late-onset myopes (onset 15 yr or later, \(n = 15\)). The rationale for separating the myopes in this way is that it has been suggested that the two groups have a different etiology, with late-onset myopia caused by environmental influences.\(^{28}\)

Each subject underwent a full binocular refraction before being assigned to a particular refractive group. All subjects could attain 6/6 visual acuity in each eye and no anisometropic or amblyopic subjects were included in the study. Also, no subjects with medium to high astigmatism (>1 D) were included in the study because ametropic observers were corrected with ultra-thin, soft contact lenses. All subjects gave their consent before participating and after a full explanation of all experimental procedures.

The tonic position of accommodation was monitored using the objective infrared autorefractor Canon Autoref R-1\(^{®}\). The major advantages offered by this instrument over the more conventionally used Badal Laser Optometer are that it is totally objective (requiring no judgment or response by the subject), presents no visual stimulus by use of infrared filters (leaving the subject in total darkness throughout the measurement procedure), and takes approximately one reading per second. The autorefractor uses the central 2.9 mm of the pupil diameter for measurement purposes. The Canon Autoref R-1\(^{®}\) has recently been evaluated and found to give a valid and reliable measurement of the refractive state of an eye.\(^{29}\)

All ametropic subjects were corrected using ultra-thin soft contact lenses, which they were allowed to adapt to before any readings were taken. The autorefractor was set for a back vertex distance of 0 mm so that all results would be ocular accommodative responses. The instrument allowed an unobstructed binocular view into the distance, and measurements were recorded on only one eye. However, the subject was unaware of which eye was being monitored.

The procedure for each subject was to line up the measuring axis of the autorefractor with the visual axis of the eye under measure, while the subject views a distant target. The subject’s head position was kept constant with aid of a head rest and bite bar, independently adjustable in the X, Y, and Z axes. Once aligned, the instrument was locked in position. The subject was returned to a binocular viewing condition and instructed to view the distant target briefly (10–15 sec) while a minimum of six readings were taken; the mean of these values were used as the baseline for calculating tonic accommodation. The room and target lights were then extinguished and the refractive state monitored at 1-min intervals for at least the next 12 min. If required, realignment of the subject’s eye with the measuring axis of the autorefractor was accomplished via randomized auditory cues from the experimenter, who could note any eye movements on the video monitor, which was viewed under cover. It was possible to detect eye movements of 0.5 deg and greater on the monitor. The room and target lights were then turned on once again, and the subject was instructed to view the distant target to confirm that alignment was maintained correctly during measurement.

Although it was attempted to align the subject’s eye exactly along the measuring axis of the autorefractor at all times during measurement, for practical purposes it was decided to allow measurements to be taken within a 2-deg radius of perfect fixation, with these limits marked on the screen. It has been stated by Johnson et al\(^{30}\) that less than a 0.25 D change in the accommodative response occurs with up to 7 deg of horizontal and vertical deviation, as measured on an infrared optometer. To confirm that a deviation of up to 2 deg had no significant effect on measurements using the Canon R-1\(^{®}\), the change in response with up
to 3 deg of deviation in the horizontal and vertical meridians was measured in five subjects, two of whom were soft contact lens wearers. The findings confirmed previous studies in showing very little change for small horizontal (3-deg deviation gave a mean change of 0.06 D) and vertical (3-deg deviation gave a mean change of 0.18 D) deviations.

This procedure was used for the first 10 subjects in each group to obtain information on the time course of tonic accommodation. For the remaining subjects in each group, after the initial measurement in total darkness, the subject was released from the head restraint and bite bar, being returned after 8 min had elapsed. Correct eye alignment with the measuring axis of the autorefractor was accomplished by auditory commands from the experimenter who could note eye position on the video monitor, which was viewed under cover. The refractive state was then monitored at 1-min intervals over the next 5 min.

The tonic accommodation value for each subject was taken as the difference between the mean of all readings recorded after 8 min in total darkness and the initial baseline reading. It is true to state that many of the hyperopic group did not habitually wear a constant correction, and thus it could be argued that they might be expected to show a greater level of tonic accommodation. However, as the tonic accommodation value was taken as the change in focus between corrected photopic vision and absolute darkness, as measured by the same technique, any constant increase in ciliary muscle tone in a normal visual environment would not affect the present results.

Results

Summary data for all 62 subjects (Fig. 1) demonstrate that accommodation does indeed adopt an intermediate resting position in the absence of visual stimulation (mean = 0.91 D, SD = 0.53 D). Figures 2 and 3 show both the mean value and distribution of the tonic position of accommodation for each of the refractive groups discussed previously. A one-way analysis of variance reveals a highly significant difference between the means (F = 8.85, P < 0.001, df = 3,58). Duncan’s multiple comparison test demonstrates that differences among refractive groups are all significant at the 5% level or above, except for the emmetropic and earlier-onset myope groups in which no significant difference was found. It is interesting to note that the distribution of tonic accommodation values was narrower for the late-onset myopes than for the other refractive groupings.

Figure 4 shows the time course of tonic accommodation for each of the refractive groups, and it is evident that the vast majority of accommodative shift occurs within the first 30 sec. For the two myopic groups and the emmetropic group, the mean tonic position stabilized after 1–2 min in darkness and showed little variation for the following 10 min. However, the mean tonic position for the hyperopic group, after the initial increase, continued to rise slowly for approximately another 6–7 min before stabilizing. This finding may not be too surprising when one considers that young hyperopes rarely wear a constant correction and, thus, in a normal visual environment will be actively accommodating, which has been shown recently to cause short-term shifts in the tonic position of accommodation. These studies have been conducted on emmetropic subjects,
however, in a recent investigation in our own laboratory, and it was found that hyperopic subjects undergo a "counteradaptive" decrease in tonic accommodation after sustained periods of close work (Fig. 3). It is feasible that the slower stabilization of the mean tonic accommodation level in hyperopes is due to the gradual decay of these counteradaptive decreases after sustained accommodative activity.

![Fig. 3.](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933365/) Frequency distributions of tonic accommodation for 15 corrected late-onset myopes, 15 corrected early-onset myopes, 17 emmetropes, and 15 corrected hyperopes.

![Fig. 4.](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933365/) The time course of tonic accommodation for 10 corrected late-onset myopes, 10 emmetropes, 10 corrected early-onset myopes, and 10 corrected hyperopes. Each point represents the mean value of tonic accommodation for the 10 subjects within each group at the particular time indicated on the abscissa.
Twenty subjects, five from each group, were re-tested at intervals of 2–20 weeks to give a measure of the stability of tonic accommodation over time. This correlation yielded a Pearson product-moment coefficient of $r = 0.93$, which agrees with previous studies (eg, Miller$^{15}$; Mershon and Amerson$^{16}$) by showing a high stability of individual tonic accommodation measures.

Discussion

The mean value of 0.91 D for the entire group, although lower than values found using laser optometry, is similar to studies employing infrared optometry (ie, Johnson et al$^{30}$ and Schor et al$^{34}$). Recent findings suggest that this discrepancy between the two techniques may be due, in part, to the effect of judging the direction of speckle motion in laser optometry.$^{35}$

The present findings confirm that corrected hyperopes do have a higher dioptric value of tonic accommodation than emmetropes or myopes. It is interesting to note that the mean values for the two myopic groups differ significantly; this result was, however, not too surprising in the light of recent findings showing significant differences in amplitude of accommodation between the two groups.$^{23}$ These findings lend further support to the suggestion that the two groups have a separate etiology, with late-onset myopia being environmental in origin and early-onset myopia essentially genetic in origin.$^{28}$ This difference between myopes may be one reason why some studies have been unable to demonstrate any clear relationship between tonic accommodation and refraction. However, previous studies have invariably investigated the data for a linear relationship between refraction and tonic accommodation, which, as demonstrated by the present results, is not the case. Indeed, for the present data the linear correlation between the two variables is low ($r = 0.24$), suggesting no direct linear relationship between degree of refractive error and tonic accommodation (Fig. 6).

A possible interpretation of these findings on tonic accommodation and refractive error has been suggested by Charman$^{36}$ based on a model of accommodation proposed by Toates.$^{37}$ Toates$^{38}$ states that the resting (or tonic) position of accommodation is determined by the equilibrium established between sympathetic and parasympathetic tone; according to this model, accommodation for distant objects is actively induced by the sympathetic system, and the parasympathetic division produces accommodation for near objects. Based on this assumption, Charman$^{36}$ suggests that myopes may have a weak sympathetic/strong parasympathetic innervation, which would tend to reduce the attainable range of response...
for more distant objects, thus rendering the subject relatively myopic. When this myopic eye is then corrected with a suitable negative lens, its tonic position of accommodation would be shifted outward to a dioptrically lower value than that of an emmetropic eye having a normal autonomic balance. Conversely a relatively strong sympathetic/weak parasympathetic innervation would result in hyperopia, with the corrected eye having a higher dioptric value of tonic accommodation. Recent work on the accommodative response as a function of stimulus, would appear to support this hypothesis. It would be predicted that not only would the tonic position of accommodation be shifted in the corrected ametropic eye, but that all points on the accommodative response curve would show a change in accommodative lag. This result has been shown to occur, with late-onset myopes having the lowest accommodative response gradient (accommodative response/accommodative stimulus) and hyperopes the highest.24

However, Garner39 argues that the converse is more likely—ie, the myopic eye would be associated with a strong sympathetic/weak parasympathetic combination. He postulates that in the growing eye a tendency to myopia would be countered by increased sympathetic innervation in an attempt to focus distant objects clearly. The low resting point for myopes thus reflects the tonus of the ciliary muscle as a result of an overactive sympathetic branch following attempted emmetropization by the eye. Similar reasoning would predict that the high tonic position for hyperopes is associated with a strong parasympathetic innervation.

Both of these explanations for the observed findings on tonic accommodation are based on the model of accommodation suggested by Toates. As mentioned, this model proposes that increased sympathetic activity is responsible for adjusting ocular focus for distance vision, and parasympathetic activity is required for near vision. This would require sympathetic-mediated distance accommodation to be as rapid as parasympathetic-mediated near accommodation. However, this is in conflict with the observations of Tornqvist3,4 who demonstrated that stimulation of the cervical sympathetic nerve of monkeys produces negative accommodation that develops slowly with a maximal effect after 10–40 sec—too slow to provide an effective temporal response to the changing stimulus requirements of a normal visual environment. It is interesting to note that Tornqvist also found that this sympathetic-mediated negative accommodation increased in effect when the underlying level of parasympathetic activity was increased. From this finding he concluded that sympathetic stimulation to the ciliary muscle was inhibitory in nature.

Recent work on the effects of tropicamide on tonic accommodation12 suggests that variations in tonic accommodation between individuals is a consequence of variations in the parasympathetic tone of the ciliary muscle. This implies that a dioptrically high tonic accommodation is indicative of a high parasympathetic tone.

Relating the preceding findings to the present results suggests that hyperopes have a high parasympathetic tone and late-onset myopes a low parasympathetic tone; emmetropes have an intermediate or possibly normal parasympathetic tone. Although it is suggested from these findings that differences in tonic levels of accommodation for the different refractive groups are possibly due to variations in the autonomic innervation to the ciliary muscle, it is feasible that the high levels of resting a focus found in the hyperopic group could be the result of previous accommodative activity in those subjects who do not habitually wear a refractive correction. However, this would not explain the high values found for the hyperopic subjects who habitually wore a refractive correction or the low values for late-onset myopes relative to early onset myopes. Also it is interesting to note that Van Alphen40 came to a similar conclusion in his monograph on the theory of emmetropization. Van Alphen proposed that a “stretch” factor ultimately determined the refractive state of the eye and the amount of stretch was controlled by the tonus of a ciliary muscle–choroid capsule that was able to resist, in part, the intraocular pressure. He demonstrated that under parasympathetic stimulation there was an increased tension in the whole choroid, which led to a decrease in pressure on the sclera, the opposite effect being found under sympathetic stimulation although to a lesser degree. From this he predicted that individuals with high levels of ciliary muscle tonus (ie, high dioptric levels of tonic accommodation) would be hyperopic, whereas persons with low levels of ciliary tonus would be myopic. Wallman et al41 suggested a similar mechanism to explain the dramatic progressive decrease in the variability of refractions (emmetropization) in growing chicks.

The answer to the apparent conflict between these interpretations of the finding that hyperopes have a dioptrically higher tonic accommodation than emmetropes or myopes, may be forthcoming from recent work on accommodative hysteresis. These studies32–34 have shown that, in emmetropes, sustained visual tasks produce shifts in the tonic position of accommodation. The relative magnitude of these shifts in tonic accommodation has been found to be
negatively correlated to the pretask tonic accommodation level. Thus, a relatively low pretask tonic accommodation level would result in a larger inward shift of the tonic position, after sustained near visual tasks, than would a relatively high pretask tonic accommodation level. If the above findings on accommodative hysteresis are related to the results of the present investigation, it would be expected that late-onset myopes would experience the largest positive (inward) shifts and hyperopes the smallest, after sustained near-vision tasks. This has indeed been found to be the case in a recent investigation in our own laboratory (article in preparation), using the same subjects and refractive grouping. After a 15-min sustained near-vision task of high cognitive demand, late-onset myopes showed marked myopic (positive) shifts in their tonic level of accommodation, whereas hyperopes surprisingly demonstrated a “counter-adaptive” decrease in their tonic level of accommodation after sustained near viewing (Fig. 5). It is also evident from Figure 5 that there is little sign of any accommodative hysteresis effects on tonic accommodation after sustained near viewing for emmetropes or early-onset myopes. One could argue that if, as Tornqvist suggests, sympathetic innervation to the ciliary muscle is inhibitory in nature, its role may be to attenuate these positive shifts in tonic accommodation after sustained near-vision tasks. This was found in three of the four refractive groups. If the proposed role of sympathetic innervation is correct, then to explain the observed differences in accommodative hysteresis between the refractive groups, a variation in the sympathetic as well as the parasympathetic innervation to the ciliary muscle, in the different groups, would need to be proposed. Support for this suggestion is given in a recent study by Stephens. Therefore the evidence so far seems to suggest that hyperopes have a high sympathetic as well as a high parasympathetic tone, and late-onset myopes have a low sympathetic and low parasympathetic resting tone when compared with emmetropes who might be classed as having a more normal ocular autonomic balance. These findings have important implications with respect to refractive development, and investigations are presently under way to elucidate further the mechanisms underlying the observed differences between refractive groups.

Key words: tonic accommodation, refractive error, parasympathetic innervation, sympathetic innervation, late-onset myopia

References

24. McBrien NA and Millodot M: The effect of refractive error on...