Differences in Adaptation of Tonic Accommodation
With Refractive State

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It has recently been demonstrated that intersubject variations in tonic (dark focus) levels of accommodation are related to corrected refractive state (McBrien and Millodot, 1987). The aim of the present study was to investigate the effect of sustained visual tasks on the tonic level of accommodation in different refractive groups. Eleven hyperopes, 16 emmetropes, ten early onset myopes and ten late onset myopes had their tonic accommodation measured with the objective infrared optometer Canon Autoref R-1 before and after a 15 min sustained visual counting task. The post-task tonic accommodation level was monitored for 15 min to assess the decay rate of any observed task-induced changes in tonic accommodation. Subjects repeated the experimental procedure for four task locations (6 m, pre-task tonic position, 37 cm and 20 cm). Late onset myopes showed significant positive (myopic) changes in their tonic level of accommodation at both near viewing distances, which showed no evidence of decay during the 15 min post-task monitoring period. Hyperopes, however, underwent transient “counteradaptive” decreases in their tonic level of accommodation after sustained near viewing. Emmetropes and early onset myopes showed little change in tonic levels at the two near distances. Differences between groups were also obtained at tonic and far viewing distances. Post-task changes in tonic accommodation demonstrated only a weak negative correlation with pre-task tonic accommodation levels at each task distance. It is proposed that the observed differences in adaptation of tonic accommodation among refractive groups may be related to variations in autonomic innervation of the ciliary muscle. Invest Ophthalmol Vis Sci 29:460-469, 1988

It is now well established that the eye adopts an intermediate resting position in the absence of visual stimulation (eg Leibowitz and Owens'). That the primary cause of this so called “anomalous myopia” is accommodation has been clearly demonstrated.2,3 The classical theory of accommodation assumes that the only active process is an increase in the refractive power of the eye mediated via parasympathetic innervation to the ciliary muscle. This concept, however, has in recent times been shown to be inaccurate. Pharmacological,4-6 electrophysiological7 and anatomical8-10 investigations have demonstrated the presence of both sympathetic receptors and sympathetic innervation of monkey and human ciliary muscle. This sympathetic innervation has been shown to be both beta receptor mediated and inhibitory in nature.4,5,7,10

An interesting feature of the tonic position of accommodation is that it exhibits considerable variation (ie 0 to 4 D) between individuals,14,15 although the value for a given individual has been shown by several studies to be remarkably stable over time.15-17 It has been suggested that the refractive properties of the eye may be related to these individual differences. This has been confirmed by a recent study18 which demonstrated clear differences between refractive groups (see Fig. 1), the observed relationship between...
tonic accommodation and refractive state being non-linear.

The possible clinical significance of these differences in tonic accommodation may be forthcoming from recent work on accommodative hysteresis. The results on the repeatability of the tonic accommodation cited above suggest that the tonic position is stable for a given individual. However, recent studies have demonstrated that the tonic position can be influenced by previous visual activity. Initial studies by Ebenholtz19,20 have demonstrated that in emmetropic observers a hysteretic shift in tonic accommodation occurs after periods of sustained viewing. From these findings the author proposed that hysteresis of tonic accommodation may be a precursor to induced myopia. In support of this, a recent study21 has also found concomitant shifts in the far point refraction associated with near task hysteresis effects on tonic accommodation. Although several studies have since confirmed this adaptability of tonic accommodation, in emmetropic subjects, with sustained viewing22,23 no such agreement has been found concerning the time course of the decay of observed shifts24 or reasons for the variability between subjects.25 Recently,20 it was reported that the relative magnitudes of these shifts in tonic accommodation for emmetropic observers are negatively correlated to the pre-task tonic accommodation level. Thus, a relatively low pre-task tonic accommodation level would result in a larger inward (myopic) shift of the tonic position, after sustained near visual tasks, than would a relatively high pre-task tonic accommodation level.

In view of the differences observed in baseline tonic accommodation between refractive groups,18 the aim of the present investigation was to determine whether differences in the magnitude of hysteretic changes in tonic accommodation, after sustained visual tasks, also occur for the different refractive groups.

Materials and Methods

The tonic position of accommodation was monitored using an objective infrared autorefractor Canon Autoref R-1. This instrument allows a totally objective measurement of the refractive state, requiring no judgement or response by the subject. It allows the subject a binocular field of view by means of a semi-silvered infrared reflecting mirror and with the appropriate use of infrared filters was adapted so that no visual stimulus was presented; thus the subject was in total darkness throughout the measurement procedure. The instrument can take and record measurements at approximately one second intervals. The Canon Autoref R-1 has recently been evaluated and found to give a valid and reliable measurement of the refractive state of the eye.26

Fig. 1. Differences in the mean dioptric value of baseline tonic accommodation for 15 corrected late onset myopes, 15 corrected early onset myopes, 17 emmetropes and 15 corrected hyperopes (from McBrien and Millodot, 1987).

The subject population consisted of 47 university students aged 18 to 27 years, with an average age of 20.5 years. Each subject underwent a full binocular refraction before he/she was assigned to one of four refractive groups, formed on the basis of factors pertaining to the theories of refractive development.27 The emmetropic group (n = 16) covered the refraction range -0.25D to +0.75D best sphere equivalent, the hyperopic group (n = 11) had ocular refractions above +0.75D and myopes were subjects whose myopia was greater than -0.25D. The myopic subjects were further subdivided into two groups, earlier onset myopes (onset of myopia 13 years or earlier, n = 10) and late onset myopes (onset 15 years or later, n = 10). The rationale for separating the myopes in this way is that it has been suggested that the two groups have a different refractive etiology, late onset myopia being caused by environmental influences.28 Also, it has been demonstrated that the two groups have significantly different accommodative responses.18 The reason for the larger number of subjects in the emmetropic group was to allow better comparison with previous studies on accommodative hysteresis, which have in the majority of cases employed only emmetropic subjects. All subjects included in the study were found clinically to be binocularly normal and asymptomatic, exhibiting no fixation disparity at either near or far viewing distances and normal vergence ranges. Subjects could attain at least 6/6 visual acuity in each eye. No subjects with astigmatism over 1D were included in the study, as ametropic subjects were corrected with ultrathin soft contact lenses. The use of contact lenses ensured that the accommodative demand for each subject in the study was virtually identical at each task distance. Subjects were allowed
approximately 30 min for the contact lenses to settle on the eye and become subjectively comfortable. Subjects were requested not to undertake any concentrated visual tasks for at least the 30 min preceding each experimental session. A full explanation of the experimental procedure was given to all subjects before entering the study and consent was obtained.

The procedure for the measurement of tonic accommodation using the Canon R-1 has been described in detail elsewhere. Briefly, the subject's eye was aligned with the measuring axis of the autorefractor with the aid of an infrared camera and video monitor. Once aligned the instrument was locked in position and the subject returned to a binocular viewing condition and instructed to briefly view a green spotlight at 6 m (see McBrien and Taylor30). An average of ten readings were taken and the mean equivalent sphere of these values was taken as the baseline for the calculation of tonic accommodation. The room lights were then extinguished and the subject allowed to adapt to the totally darkened environment for 10 min. The subject was then returned to the bite bar and the refractive state monitored at 1 min intervals for the next 5 min; a minimum of six readings were taken at each time interval. The room lights were then turned on and the subject released from the bite bar.

The pre-task tonic accommodation value was taken as the difference between the mean of all readings recorded in total darkness (10–15 min) and the mean of the initial baseline readings. The subject was then positioned to carry out the sustained visual task, and the distance was kept constant with the aid of a head and chin rest. The task was a concentrated counting exercise consisting of a series of cards containing rows of simple numbers which had to be added, subtracted or multiplied. The subject was required to perform calculations audibly so that accurate fixation and compliance to the task could be monitored. The task was designed to have high cognitive demand and thus replicate stressful near task situations, which have been suggested by several studies to affect the accommodative response.31,32

After 15 min of the sustained visual task the room lights were extinguished without warning and the subject returned to the bite bar apparatus. In all subjects, readings of post-task tonic accommodation were recorded at 45 seconds to 1 min post-task; a minimum of 10 readings were taken. Readings were also recorded at 7 and 15 min post-task to obtain information on the time course of any observed shifts. To obtain a more complete picture of the time course of any post-task changes in tonic accommodation, five subjects from each group and ten from the emmetropic group had their post-task tonic accommodation monitored at more frequent intervals during the 15 min post-task monitoring period. Subjects were in complete darkness throughout the post-task monitoring period.

Each subject repeated the experimental procedure on four separate occasions, once for each task location (ie 6 m, pre-task tonic position, 37 cm and 20 cm). Experimental sessions were separated by at least 2 days. The sequence of task distances was presented to subjects randomly in a balanced array to reduce the possibility of learning effects within groups. The size of the visual detail used at each task distance was photographically varied so as to subtend a constant visual angle of 1.5 min of arc at the eye. The luminance of the task was controlled so as to give approximately equal luminance at each distance, varying between 150 and 200 cd/m².

Results

The results of post-task changes in tonic accommodation for each refractive group, after sustained viewing at each of the four task locations, are shown in Figures 2 to 5.

Figure 2A presents the mean task-induced changes in tonic accommodation for the four refractive groups after 15 min of sustained viewing at the closest distance of 20 cm. It is evident that marked differences in post-task shifts in tonic accommodation occurred between groups. The late onset myopic group showing a significant myopic shift while the hyperopic group surprisingly demonstrated a “counteradaptive” decrease in their tonic level of accommodation. Neither the emmetropic nor the early onset myopic group showed a significant shift after sustained near viewing. It is pertinent to note the marked difference in responses between the two myopic groups. This finding is in agreement with earlier investigations which have documented differences in other aspects of the accommodative response between early and late onset myopes.3,29 A one-way analysis of variance (ANOVA) revealed significant differences in accommodative hysteresis between groups for the initial post-task monitoring period (F = 10.50; P < 0.001), differences between individual groups, using Duncan’s multiple comparison test, were all significant at P < 0.05 or greater, except between the emmetropic and early onset myopic group. These differences between groups were evident throughout the post-task monitoring period. A similar trend was also found for the time course of the decay of post-task changes for the subjects who were monitored at more frequent intervals during the 15 min post-task period. This was also found to be the case at the other task locations. Figure 2B illustrates the post-task change as a function of the pre-task tonic accomm-
Fig. 2. (A) The mean task induced changes in tonic accommodation levels for late onset myopes (LOM), early onset myopes (EOM), emmetropes (EMM), and hyperopes (HYP), after 15 min sustained viewing at 20 cm. Error bars represent ±1 SEM. (B) The relationship between post-task changes in tonic accommodation, after 15 min sustained viewing at 20 cm, and the pre-task tonic accommodation level for all subjects.

dation level for all subjects, at the 20 cm viewing distance, producing a negative correlation of −0.29 (P = 0.05).

Figure 3A presents the results of the more standard close viewing distance of 37 cm, which as can be seen are qualitatively similar, although of smaller magnitude, to results at 20 cm. A one-way ANOVA of the mean values of post-task changes in tonic accommodation for each refractive group revealed significant differences (F = 4.23; P < 0.02), which were also evident at the subsequent post-task measurement times. It is interesting to note that the change in the tonic accommodation level for the late onset myopic group, observed at both near viewing distances, showed no sign of decay over the post-task monitoring period. Figure 3B plots the post-task change in tonic accommodation as a function of the pre-task tonic accommodation level, for the 37 cm viewing distance, producing a negative correlation of −0.51 (P < 0.001).

When the task is placed at the observers pre-task tonic accommodation position it was found that three of the four refractive groups showed very little change in their tonic level of accommodation after 15 min of sustained viewing (see Fig. 4A). The hyperopic group, however, showed a marked decrease in their tonic level of accommodation. This shift, which occurred in all 11 subjects, decayed back to baseline by the end of the post-task monitoring period. As task distance was set at each individual's pre-task tonic level, the above finding may suggest that not only is the task distance an important factor, but also that the stressful or cognitive nature of the task may affect the accommodative response, as inferred by data from previous studies.31,32 A one-way ANOVA revealed significant differences in hysteresis between the groups for the 1 min (F = 4.78; P < 0.01) and 7 min (F = 4.58; P < 0.01) post-task monitoring intervals but no significant difference at the 15 min post-task interval. These differences were due solely to changes found for the hyperopic group. A nonsignificant negative correlation of −0.28 (P > 0.05) was found when post-task change was plotted as a function of pre-task tonic accommodation value, when the task is placed at the observer's tonic position.

Figure 5A shows the mean task-induced changes in tonic accommodation levels for the four refractive groups, after 15 min of sustained viewing at a task distance of 6 m. All groups demonstrated a shift towards the task, which was substantial for all but the late onset myopic group. This finding would be difficult to explain on the basis of the classical single innervation theory of accommodation and thus lends strong support to a dual innervation (i.e., involvement of sympathetic as well as parasympathetic innervation) theory of accommodation. For the three groups
Fig. 3. (A) The mean task induced changes in tonic accommodation levels for late onset myopes (LOM), early onset myopes (EOM), emmetropes (EMM), and hyperopes (HYP), after 15 min sustained viewing at 37 cm. Error bars represent ±1 SEM. (B) The relationship between post-task changes in tonic accommodation, after 15 min sustained viewing at 37 cm, and the pre-task tonic accommodation level for all subjects.

Fig. 4. (A) The mean task-induced changes in tonic accommodation levels for late onset myopes (LOM), early onset myopes (EOM), emmetropes (EMM), and hyperopes (HYP), after 15 min sustained viewing of a task placed at the observer's pre-task tonic position. Error bars represent ±1 SEM. (B) The relationship between post-task changes in tonic accommodation, after 15 min sustained viewing at the observer's pre-task tonic position, and the pre-task tonic accommodation level for all subjects.
Fig. 5. (A) The mean task-induced changes in tonic accommodation levels for late onset myopes (LOM), early onset myopes (EOM), emmetropes (EMM), and hyperopes (HYP), after 15 min sustained viewing at 6 m. Error bars represent ±1 SEM. (B) The relationship between post-task changes in tonic accommodation, after 15 min sustained viewing at 6 m, and the pre-task tonic accommodation level for all subjects.

who showed marked hyperopic shifts (ie, early onset myopes, emmetropes, and hyperopes), only two of the 37 subjects did not show an adaptive change towards the task position. It is interesting to note that although the dioptric separation between task stimulus and pre-task tonic accommodation level is only approximately 1D for far viewing, compared to 4D at near viewing (20 cm), there are significantly greater changes in tonic levels of accommodation for the three above-mentioned groups. A one-way ANOVA of the initial (1 min) mean changes revealed significant differences between the groups (F = 4.49; P < 0.01), which were also evident at the subsequent post-task measurement intervals. Figure 5B illustrates the post-task change in tonic accommodation levels as a function of the pre-task value; for the 6 m viewing distance, once again a negative correlation (−0.37; P < 0.01) was obtained.

As pre-task tonic accommodation values were recorded at each experimental session, it was possible to investigate the relationship between baseline tonic accommodation and refractive state. It was found that the mean value of pre-task tonic accommodation was dioptrically highest for hyperopes and lowest for late onset myopes at each of the four measurement sessions. The mean values for the emmetropic and early onset myope group were intermediate and very similar in each case. A one-way ANOVA of pre-task tonic accommodation values between groups was found to be highly significant (P < 0.01) for each measurement session. These results add strong support to previous findings reporting a similar relationship between tonic accommodation and refractive state.

As demonstrated above, the mean pre-task tonic accommodation values were significantly different between groups and thus when the task was placed at a constant location (ie, 20 cm, 37 cm and 6 m), the distance between pre-task tonic level and task would be variable between groups and subjects. It was therefore pertinent to determine whether the observed differences in accommodative adaptation at these distances were solely due to differences in pre-task tonic accommodation values. Analysis of covariance was used to adjust statistically for differences in the pre-task tonic levels. A highly significant difference in
accommodative hysteresis was still obtained between groups for the 20 cm sustained viewing distance (F = 7.606, P < 0.001), but statistical significance, at the 5% level, was not obtained for the 37 cm or 6 m viewing distances.

To give a measure of the repeatability of the post-task changes in tonic accommodation after sustained viewing, ten subjects, consisting of at least two from each refractive group, repeated the experiment for one of the task distances, all distances being represented. Comparison of initial and retest values for post-task changes in tonic accommodation at the 1 min interval revealed a correlation of r = 0.92 (see Fig. 6). In all individual cases the task-induced change in tonic accommodation was in the same direction and of a similar order of magnitude. The time course of observed changes was also found to be similar over the 15 min post-task monitoring period.

It is also possible to make some comment about the repeatability and stability of baseline (pre-task) tonic accommodation measures. For subjects who completed all experimental sessions (n = 47) it was found that comparison of values for each subject, between different measurement sessions, gave correlation coefficients of between 0.77 and 0.83. This demonstrates a high and consistent level of repeatability. This finding supports the validity of using baseline tonic accommodation levels as a reference point for the accommodative system of an individual.

Discussion

It is evident from Figures 2 to 5 that marked differences in task-induced changes in tonic levels of accommodation occurred between the various refractive groups. It is also clear that the time course of observed shifts in tonic levels varied with respect to refractive group and task distance. These significant differences between refractive groups may well explain some of the inconsistencies between previous studies and also some of the hitherto unexplained differences between subjects within a single study. To the authors' knowledge this is the first study to demonstrate a relationship between adaptation of tonic accommodation and refractive state.

It is interesting to speculate on the possible mechanisms to explain the observed differences in accommodative adaptation between refractive groups. The absence of any significant hysteresis effects, after sustained near viewing, in emmetropic and early onset myopic observers, and counteradaptive shifts in hyperopes, may suggest the presence of some mechanism which attenuates or reduces any unacceptable changes in tonic accommodation. However, the results at the 6 m viewing distance would seem to suggest that any mechanism responsible for attenuating or reducing changes after sustained near viewing does not operate as effectively for sustained far viewing.

There is a consistent body of evidence to support a small but definite sympathetic innervation of primate ciliary muscle. The functional importance of this sympathetic innervation of ciliary muscle is, as yet, not clearly defined. One possible function is suggested from the work of Tornqvist and Hurwitz et al. Tornqvist demonstrated that stimulation of the preganglionic cervical sympathetic nerve in monkeys produces negative accommodation, which developed slowly with a maximal effect after 10–40 seconds. It was also noted that the level of sympathetically mediated negative accommodation was dependent on the concurrent level of parasympathetic activity. The greatest inhibitory levels of negative accommodation (max 1–2D) were produced when there was a high background parasympathetic activity. Both studies concluded that the function of sympathetic innervation of primate ciliary muscle was inhibitory in nature. Due to the slow time course of the effect and its inhibitory nature it could be argued that the role of sympathetic innervation is more likely to be associated with sustained periods of accommodation.

It seems feasible to propose, from the evidence cited, that the attenuative or protective function discussed earlier is accomplished via inhibitory sympathetic innervation of the ciliary muscle. Although it would be expected that some smooth muscle tone would be retained after sustained near viewing, which would reflect in a dioptric increase in tonic accommodation, the longer decay rate of inhibitory sympathetic stimulation (Tornqvist found it took 5 to 20 seconds after ending stimulation before the effect had elapsed completely) may be sufficient to reduce any increase in parasympathetic resting tone, as measured 45 seconds after cessation of the task.

However, in order to explain the marked differ-
ences between groups one would have to assume some variation in the strength or effectiveness of this mechanism. One possible source of this variation could be differences in the strength of sympathetic and parasympathetic innervation of the ciliary muscle. Based on this hypothesis one would expect reduced sympathetic innervation to result in less protection against accommodative hysteresis, after sustained near viewing. In the present study the only group to show significant accommodative hysteresis after sustained near viewing was the late onset myopic group, who interestingly were the only group not to show significant accommodative hysteresis after sustained distance viewing. In this context it is noteworthy to recall the work of Cogan. He demonstrated that subjects with damage to the cervical portion of the sympathetic system showed increased accommodative amplitude, and concluded that reduced sympathetic innervation impedes distance accommodation but enhances near accommodation. In a previous study by the present authors it was found that late onset myopes have significantly greater amplitudes of accommodation than any of the other refractive groups included in the present study. This would seem to suggest, in view of Cogan’s findings, that late onset myopes have either a reduced ciliary muscle sympathetic innervation or a reduced sympathetic capability. Conversely, the results for hyperopes suggest a very strong inhibitory mechanism, which, based on the above reasoning, may be indicative of a strong sympathetic innervation or facility. The results from the hyperopic group, while being in agreement with the above hypothesis, are possibly confounded by the unknown effects that previous spectacle-wearing history may exert. While both groups of myopes habitually wore a refractive correction which was optimal or near optimal, only seven of the 11 hyperopic subjects habitually wore a near optimal correction. However, it is argued that the conformity of results within this group suggest that spectacle-wearing history was not an important variable, although it should be borne in mind when interpreting results.

The suggestion of variation in the autonomic innervation to the ciliary muscle has been put forward by previous studies in relation to other aspects of accommodation. The latter study suggesting that the intersubject variation in baseline tonic accommodation was predominantly due to variation in parasympathetic tone of the ciliary muscle. Related to the present study, this infers that hyperopes have the greatest parasympathetic resting tone and late onset myopes the lowest, as has been previously proposed by the present authors. It is interesting to recall that when the variation in baseline tonic accommodation was accounted for in the present study, a significant difference in hysteresis of tonic accommodation was still obtained between groups for the closest viewing distance of 20 cm. As this task distance induced the greatest parasympathetic activity, it might be expected to also induce the greatest inhibitory sympathetic effect. Therefore, assuming intersubject variation in the effectiveness of autonomic innervation of the ciliary muscle during accommodation, one would anticipate that differences in accommodative hysteresis between groups would be most apparent at the 20 cm viewing distance. It is pertinent to note that previous studies have suggested that variation in baseline tonic accommodation is predominantly due to variation in parasympathetic tone, while the present study proposes that variations in post-task shifts in tonic accommodation after sustained near viewing are predominantly due to variations in the sympathetic system.

The results of the present investigation have obvious implications with respect to refractive development. It has previously been suggested that hysteresis of tonic accommodation may be a precursor to myopia. If this is indeed the case then it would seem feasible to propose that the most likely subjects to undergo positive hysteresis of tonic accommodation after sustained near viewing would be myopes. The present results would appear to partially support this hypothesis. Specifically it was found that, as a group, only late onset myopes demonstrated significant myopic shifts in tonic accommodation after near viewing. It is proposed that this difference in accommodative hysteresis between early and late onset myopes is due to the reduced sympathetic capability of late onset myopes. It is interesting to speculate whether this reduced sympathetic capability is an environmental or genetic trait. While previous studies have suggested that late onset myopia is caused by environmental influences (eg excessive close work), if the predisposing factor is a reduced sympathetic inhibitory input, it is possible that this could be a genetic trait.

One of the factors upon which early and late onset myopes are separated is on the basis that the eye has normally reached adult axial dimensions by the age of 13 years. From this it is implied that late onset myopia is unlikely to be axial in nature and indeed, it has in fact been suggested to be due to lenticular changes. A recent investigation by the present authors, however, has clearly demonstrated that the ultimate cause of late onset myopia (average age of onset 18 years) is vitreous chamber elongation, although some lenticular differences were also found. If, as previous studies have proposed, hysteresis of tonic accommodation is a precursor to myopia, then
it would appear that a mechanism causing axial elongation is implicated. In this respect it is interesting to recall that several studies have presented evidence to support an increase in vitreous chamber pressure during accommodation, both in monkeys and humans.\textsuperscript{31,32,39-41} This has been suggested to cause an eventual increase in vitreous chamber depth, resulting in myopia.\textsuperscript{34,35} The long duration of increased parasympathetic tone after near work, observed for the late onset myopic group of the present study, may possibly support the feasibility of such a mechanism of axial elongation, especially in light of the recent findings of Schor et al.,\textsuperscript{48} which suggest that darkroom measures of adaptation of tonic accommodation are conservative estimates compared to other open loop measures (ie, Maxwellian view). Also, in a recent study on kittens by Hendrickson and Rosenblum,\textsuperscript{49} it has been demonstrated that chronic physiological measures of sustained accommodation (1–2D) can indeed cause axial elongation.

It is clear, however, that further investigations are required before any conclusions can be drawn as regards the tenuous links between adaptation of tonic accommodation and refractive development. Longitudinal studies on accommodative adaptation should provide a clearer insight into possible long-term consequences of sustained visual tasks, especially if coupled with biometric data. There is also a clear need to obtain a better understanding as to the precise function of sympathetic innervation in ocular accommodation. Investigations on animal models of refractive development and accommodation should also yield valuable information to help further unravel the complexities of refractive development and change.

Key words: accommodative adaptation, late onset myopia, sympathetic innervation, parasympathetic innervation, tonic accommodation

References