Axial elongation following prolonged near work in myopes and emmetropes

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ABSTRACT

Background/aims: To investigate the influence of a period of sustained near work upon axial length in groups of emmetropes and myopes.

Methods: Forty young adult subjects (20 myopes and 20 emmetropes) were recruited for the study. Myopes were further classified as either early onset (EOM), late onset (LOM), stable (SM) or progressing (PM) subgroups. Axial length was measured with the IOLMaster instrument before, immediately after and then again 10 minutes after a continuous 30 minute near task of 5 D accommodation demand. Measures of distance objective refraction were also collected.

Results: Significant changes in axial length were observed immediately following the near task. EOM axial length elongated on average by 0.027 ± 0.021 mm, LOM by 0.014 ± 0.020 mm, EMM by 0.010 ± 0.015 mm, PM by 0.031 ± 0.022 mm, and SM by 0.014 ± 0.018 mm. At the conclusion of the 10 minute regression period, axial length measures were not significantly different from baseline values.

Conclusion: Axial elongation was observed following a prolonged near task. Both EOM and PM groups showed increases in axial length that were significantly greater than emmetropes.
INTRODUCTION

Myopia is one of the leading causes of vision impairment in the world and a significant public health concern.[1-3] While the exact aetiology of myopia is not known, it is thought to have both genetic and environmental components. Near work has been recognised as one the principal environmental factors underlying the development and progression of myopia.[4-7] The association between near work and myopia has led to many studies investigating the apparent inaccuracies of the accommodative system in some myopes. Myopes have been found to exhibit accommodative lags,[8] esophoria at near and high AC/A ratios[9] compared with emmetropes, while progressing myopes may show reduced accommodative responses compared with stable myopes.[10, 11]

Partial coherence interferometry (PCI) has been used to investigate whether accommodation leads to short term changes in eye length. Drexler et al[12] investigated the effect of a short period of maximum accommodation on axial length in groups of emmetropes and myopes and found small increases in axial length that were more pronounced in emmetropes than myopes. Mallen et al[13] used a larger cohort of emmetropes and early-onset myopes and controlled the accommodative demand between groups. Transient increases in axial length were again observed during accommodation, but in contrast to Drexler et al,[12] the greatest magnitude of elongation was observed in myopic eyes. Given that myopia typically develops and progresses as a result of axial elongation of the vitreous chamber, it has been suggested that this transient elongation of the eye associated with accommodation may be an important factor in the aetiology of myopia.[12, 13]
Atchison and Smith[14] suggested that the IOLMaster instrument might erroneously overestimate axial length measurements collected during accommodation. As the IOLMaster utilises an average ocular refractive index to convert optical distances into geometric distances, the increase in crystalline lens thickness that occurs during accommodation will lead to an increase in the eye’s effective refractive index, and a subsequent increase in optical path length and hence a slight overestimation of eye length.

Whilst measures of eye length captured during accommodation with PCI may be prone to an overestimation of axial length, no previous study has investigated changes in eye length immediately following a period of near work. Given that the accommodation system relaxes quickly, we considered that errors associated with axial length measures due to lens thickness changes will likely be greatly minimised if eye length measures are collected immediately after a sustained near work task. The purpose of this study was therefore to investigate the changes in axial length occurring immediately after a sustained near task in emmetropes and myopes.

**METHODS**

Forty young, healthy adult subjects aged between 18 and 33 years (mean age 23.4 ± 4.0 years, emmetropes 23.5 ± 3.9 years, myopes 23.2 ± 4.1 years) were recruited for the study. The subjects were primarily recruited from the staff and students of the QUT, School of Optometry. All subjects were screened to exclude any history of significant ocular or systemic disease, injury or surgery. Before testing, subjects were questioned on their refractive history, and underwent a brief eye examination to ascertain subjective refraction, binocular vision status and ocular health. The subjects were classified as either emmetropes (EMM, n = 20, spherical equivalent +0.25 to -0.75 DS, with no more than -1.00 DC), or
myopes ($n = 20$, spherical equivalent $>-1.00$ DS, with no more than $-1.00$ DC). Subjects who developed myopia at age twelve or younger were classified as early-onset (EOM, $n = 10$), and those over twelve, as late-onset (LOM, $n = 10$). The myopic subjects were further divided into either stable ($n = 12$, including 9 LOMs and 3 EOMs) or progressing myopes ($n = 8$, including 1 LOM and 7 EOMs), based on previous refractive prescriptions supplied by the subjects’ primary eye care practitioner. A change in spherical equivalent of $-0.50$ D or more over the past two years was used to classify a subject as a progressing myope (PM), while the remaining myopes were classified as stable (SM).

The subjects’ mean best sphere refraction $\pm$ SD for the right eye was EMM $-0.10 \pm 0.23$ D and myopes $-3.11 \pm 2.24$ D. The mean refraction of the myopic sub-groups were, EOM $-4.54 \pm 1.93$ D, LOM $-1.69 \pm 1.53$ D, and PM $-4.36 \pm 1.84$ D, SM $-2.28 \pm 2.15$ D. All subjects exhibited a best-corrected visual acuity of 0.00 logMAR or better. Approval from the university human research ethics committee was obtained before commencement of the study and subjects gave written informed consent to participate.

Axial length was measured before, and then immediately after a 30 minute near task and then again 10 minutes after the near task had ended. All measurements were taken on the right eye only, but all tasks were performed in a natural binocular state with full sphero-cylindrical refractive correction. To ensure relaxed accommodation and minimise the influence of prior visual tasks, subjects were required to watch a television at a distance of 6 m in primary gaze for 30 minutes while wearing their distance refractive correction prior to any measurements. Baseline measurements of axial length were then captured before commencement of the near task. Subjects were then asked to read a passage of text (12 point font) on a computer monitor at a distance of 50 cm, accommodating through -3 D lenses in a trial frame over their distance.
prescription. Subjects maintained this 5 D level of accommodation over the next 30 minutes, and were positioned in a chin rest to ensure primary (horizontal) gaze was maintained for the duration of the task. At the end of 30 minutes, axial length was remeasured, with measures captured as quickly as possible following the task. We estimate that the average time required after the near task to collect the axial length measurements was 30 seconds. The subjects then watched television through their distance prescription for a further 10 minute “regression” period before a final set of measurements were taken.

Axial length was measured with the IOLMaster (Zeiss Meditec, Jena, Germany), a non-contact instrument that employs partial coherence interferometry (PCI).[15, 16] Five measurements of axial length were performed on the subjects’ right eye, with any measures displaying a signal-to-noise ratio of less than 2.0 discounted and re-taken. These five measures were averaged for each time interval for each subject.

In addition to the axial length measurements, in order to determine the magnitude of any residual accommodation following the near task, each subjects’ distance ocular refraction was also measured at each session (immediately following the axial length measures) using the Complete Ophthalmic Analysis System (COAS) (Wavefront Sciences, Albuquerque, USA) aberrometer. Four measurements, each at 10 Hz (40 wavefront measures in total) were taken for each subject at each session. The wavefronts were fitted with Zernike polynomials up to the 8th radial order and exported in OSA format. Using custom-written software, the COAS wavefront files were converted to refractive power and the best fitting refractive power sphero-cylinder was calculated over both 3 and 5 mm pupil sizes.[17]
Axial length data were averaged for each subject and the change in axial length from baseline was calculated. To investigate the significance of changes in group mean axial length, a repeated-measures ANOVA was performed.

**RESULTS**

The emmetropic group displayed a group mean baseline axial length of 23.87 ± 0.60 mm, compared to the myopic group who had a longer mean axial length of 24.64 ± 1.14 mm. The myopic subgroups had a longer mean baseline axial length than the emmetropes, with the EOM averaging 25.14 ± 1.15 mm and the LOM averaging 24.13 ± 0.91 mm. The EOM baseline axial length was significantly longer than the group average (p < 0.001). When we considered the myopic population in terms of refractive error progression, PM showed a mean axial length of 25.04 ± 1.04 mm, compared to SM with a mean axial length of 24.36 ± 1.16 mm. The mean baseline axial length of the progressing myopes was significantly longer than that of the emmetropes (p < 0.05) (Table 1).

For all forty emmetropes and myopes considered together, the group mean axial length was found to increase immediately following the task by an average of 0.015 ± 0.019 mm, with an average change from baseline after the 10 minute regression period of 0.0003 ± 0.018 mm. Repeated-measures ANOVA revealed this change in axial length after the task to be highly significant for the total group (p < 0.001), and that after the regression period of 10 minutes, axial length was not significantly different to baseline (p > 0.05). There was no significant interaction between time and refractive error group for the emmetropes and all myopes, however the difference approached significance (p = 0.09). A significant time-refractive group interaction was found between the emmetropes and myopic sub-groups (p < 0.05), indicating a different pattern of axial length change following the near task between the
groups. Pairwise comparisons with Bonferroni correction, demonstrated that the transient axial elongation following prolonged accommodation was significantly greater (p < 0.05) for EOM and PM groups compared to the EMM group (Figures 1 and 2). There was no significant difference noted between the EOM and LOM (p = 0.27) or PM and SM (p = 0.12).

**Table 1** Summary of mean axial length at baseline, change from baseline immediately after the near task, and change from baseline 10 minutes after the near task for all refractive groups. All measurements are in millimeters.

<table>
<thead>
<tr>
<th></th>
<th>EMM (n=20)</th>
<th>Myopes</th>
<th>All Myopes (n=20)</th>
<th>Age of Onset</th>
<th>Progression Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>EOM (n=10)</td>
<td>LOM (n=10)</td>
<td>SM (n=12)</td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Mean ± SD)</td>
<td>23.87 ±</td>
<td>24.64 ±</td>
<td>25.14 ±</td>
<td>24.13 ±</td>
<td>24.36 ±</td>
</tr>
<tr>
<td></td>
<td>0.60</td>
<td>1.14</td>
<td>1.15</td>
<td>0.91</td>
<td>1.16</td>
</tr>
<tr>
<td><strong>Change</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post 0 min</td>
<td>0.010 ±</td>
<td>0.020 ±</td>
<td>0.027 ±</td>
<td>0.014 ±</td>
<td>0.014 ±</td>
</tr>
<tr>
<td>(Mean ± SD)</td>
<td>0.015</td>
<td>0.020</td>
<td>0.021</td>
<td>0.020</td>
<td>0.018</td>
</tr>
<tr>
<td><strong>Change</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post 10 min</td>
<td>0.001 ±</td>
<td>-0.001 ±</td>
<td>-0.005 ±</td>
<td>0.004 ±</td>
<td>0.001 ±</td>
</tr>
<tr>
<td>(Mean ± SD)</td>
<td>0.018</td>
<td>0.019</td>
<td>0.018</td>
<td>0.021</td>
<td>0.021</td>
</tr>
</tbody>
</table>

There was a weak, but statistically significant positive correlation between myopia progression rate and axial elongation immediately following the near task (Pearson’s correlation $r^2 = 0.2$, p < 0.05). Subjects with higher myopia progression rates in the previous two years tended to show greater axial elongation following accommodation. However, the overall level of myopia (in terms of axial length or mean spherical equivalent power) did not show a significant association with transient axial elongation following accommodation (both
There was also no significant association between the change in axial length immediately following the near task and the change in ocular refraction (i.e. the amount of nearwork induced transient myopia) following the task (p>0.05).

Analysis of the ocular refraction best sphere data from the COAS wavefront sensor revealed similar trends for the 3 and 5 mm pupil sizes, therefore only the 5 mm values are presented (Table 2). Following the near task, the combined emmetrope and myope group averaged a myopic shift of -0.19 ± 0.23 D, which partly decayed over the next 10 minutes to a value of -0.14 ± 0.21 D, indicative of small amounts of NITM present following the near task. Group changes in refraction are presented in Table 2.

**Table 2** Summary of mean baseline ocular refraction best sphere, change from baseline immediately after the near task, and change from baseline 10 minutes after the near task for all refractive groups. All measurements are in dioptres (D).

<table>
<thead>
<tr>
<th></th>
<th>EMM (n=20)</th>
<th>Myopes All (n=20)</th>
<th>Age of Onset</th>
<th>Progression Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>-0.43 ±</td>
<td>-3.30 ±</td>
<td>-4.66 ±</td>
<td>-2.23 ±</td>
</tr>
<tr>
<td>(Mean ± SD)</td>
<td>0.38</td>
<td>2.15</td>
<td>1.84</td>
<td>1.70</td>
</tr>
<tr>
<td>Change Post 0 min</td>
<td>-0.18 ±</td>
<td>-0.20 ±</td>
<td>-0.11 ±</td>
<td>-0.29 ±</td>
</tr>
<tr>
<td>(Mean ± SD)</td>
<td>0.24</td>
<td>0.22</td>
<td>0.21</td>
<td>0.20</td>
</tr>
<tr>
<td>Change Post 10 min</td>
<td>-0.17 ±</td>
<td>-0.12 ±</td>
<td>-0.01 ±</td>
<td>-0.23 ±</td>
</tr>
<tr>
<td>(Mean ± SD)</td>
<td>0.18</td>
<td>0.24</td>
<td>0.21</td>
<td>0.22</td>
</tr>
</tbody>
</table>
DISCUSSION

We have shown that a significant ocular axial elongation occurs in young adult subjects following a period of sustained near work. This work extends that of previous authors who have found significant axial elongation during accommodation,[12, 13] by demonstrating that axial elongation also persists for a short period after the cessation of accommodation. Interestingly, the sub-groups of myopes showed significant differences in the amount of axial elongation, with early onset myopes and progressing myopes exhibiting larger magnitudes of change following near work. Ten minutes after the accommodation task, the axial length of the eye had returned to baseline levels. Each subject’s accommodative response was not measured during the near task, however, based upon target vergence and spectacle lens effectivity, we calculated the mean accommodative demand at the corneal plane to be 4.33 D for our myopes and 4.69 D for our emmetropes. Given the lower effective accommodative demand and previously documented larger magnitude of accommodative lags in myopes [11, 12], it is likely that the magnitude of accommodation during the near task would have been slightly lower in our myopes. In spite of this, the early onset and progressing myopes still exhibited a larger magnitude of axial elongation following the accommodation task.

As our measurements were collected immediately following the near task, our axial length measures are unlikely to be substantially influenced by the potential for slight overestimation of axial length, associated with measurements collected during accommodation with the IOLMaster.[14] Our ocular refraction measures suggest that a small amount of residual accommodation was still present following the near task (about 0.2 D). Biometric changes in the crystalline lens are known to be linearly related to dioptric accommodative changes.[18, 19] Ostrin et al[18] found ~ 67 µm of increase in lens thickness to occur per dioptr of
accommodation in young adult subjects. The 0.2 D of NITM, likely to be due to residual accommodation following the near task in our subjects therefore represents \( \sim 13 \, \mu m \) of lens thickness increase. Using the formulae from Atchison and Smith[14] and the Gullstrand no.1 model eye, a 13 \( \mu m \) change in lens thickness would lead to <1 \( \mu m \) of error in axial length calculation, which would not substantially influence our results. The fact that no significant association was found between the change in eye length and the change in ocular refraction also supports this notion.

The trends that we observed in our early onset myopes, are similar to those reported by Mallen et al.[13] although smaller in magnitude. The smaller values obtained in our study compared to Mallen et al.’s[13] cohort may be due to the rapid decay of axial elongation which may have occurred between completion of the near task and measurement of axial length. Mallen et al[13] measured axial elongation during accommodation while we measured axial elongation immediately after accommodation, although approximately a 30 second delay occurred between task cessation and measurement commencement.

We divided our myopic subjects into either stable or progressing subgroups and found that the progressing myopes showed the largest axial elongation of any group immediately following the near task. A weak but significant association was also found between change in axial length immediately following the task and myopia progression rate in the prior two years, with higher amounts of elongation noted in myopes with higher progression rates. These findings could be interpreted in many ways. They could suggest that the biomechanical structure of the progressing myopes eyes are more susceptible to axial elongation, or that the forces generated by accommodation are greater in the progressing myopes eyes, or that
optical changes associated with accommodation in the progressing myopes eyes are leading to greater short term axial elongation.

Our research group has also recently investigated axial length changes occurring during a brief period of accommodation in a different population of myopic and emmetropic subjects, using a different optical biometer (the Lenstar LS 900)[20]. Consistent with our current findings of axial elongation following a prolonged near task, we also found significant axial elongation occurs during a brief period of accommodation [20]. However, in contrast to the findings of our current study where a greater magnitude of axial elongation was found in early onset, and progressing myopic refractive groups following a prolonged near task, no difference was found between refractive groups in terms of the magnitude of axial elongation occurring during a brief accommodation task. This difference in findings suggests that the time-course of near work induced axial elongation between myopes and emmetropes may differ, and highlights the need for further research investigating the characteristics of the changes in axial length associated with near work. It should also be noted that the populations of subjects tested in the two studies were different, with the myopic subjects in our current study exhibiting substantially higher degrees of myopia (mean -3.11 ± 2.24 D) than the myopic subjects tested in our investigation of axial elongation during a brief accommodation task (mean -1.82 ± 0.84 DS), which leaves open the possibility that ocular changes associated with higher magnitudes of myopia underlie some of the difference between refractive error groups found in our current study.

Both Drexler et al[12] and Mallen et al[13] hypothesize that axial elongation during accommodation may be caused by the mechanical effects of contraction of the ciliary muscle. Mallen et al[13] suggest that reduced ocular rigidity associated with myopia allows for
greater transmission of ciliary muscle force to the choroid and sclera, as the sclera is more extensible. Changes in scleral structural, biochemical and biomechanical properties have previously been documented to be associated with myopia[21] which may therefore explain the differences observed between emmetropes and myopes in our study. Recently, investigations of ciliary body thickness between myopes and emmetropes using ultrasound biomicroscopy and optical coherence tomography have revealed that ciliary body thickness increases with increasing axial length and myopia.[22-24] It is possible that this anatomical variation may lead to differences in the forces of the ciliary muscle associated with accommodation, or differences in how efficiently the ciliary muscle force is transmitted to the choroid and sclera.

In conclusion, we have confirmed that young adult myopic and emmetropic subjects show an increase in axial length associated with accommodation. This elongation persists for a short period after near work, but 10 minutes after a 30 minute 5 D accommodation task, the axial length has returned to near baseline levels. We found that certain subgroups of myopes seem to be more susceptible to this transient elongation, both EOM and PM groups showed increases in axial length following a prolonged near task that were significantly greater than emmetropes. A weak but significant correlation was also found between higher progression rates of myopia and increased axial elongation following near work. Further studies are required with simultaneous measurement of axial length and refraction (both during and following near work) to more thoroughly characterise the time course of eye length change and to explore the interaction between changes in eye length and near work induced changes in refraction.
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REFERENCES


**FIGURE CAPTIONS:**

**Figure 1** Mean change in axial length from baseline immediately after and 10 minutes after the near task when the myopes are classified based on age of onset. All values are expressed in millimetres and error bars represent standard error of the mean.

**Figure 2** Mean change in axial length from baseline immediately after, and 10 minutes after the near task, with the myopes considered in terms of progression rate. All values are expressed in millimeters and error bars represent the standard error of the mean.