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# Open-loop accommodation in emmetropia and myopia

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## Abstract

*Purpose.* To investigate the influence of method of measurement and refractive error on the open-loop accommodation response.

*Methods.* Open-loop accommodation was measured in darkness (dark accommodation, DA) and using a pinhole pupil (pinhole accommodation, PA) in emmetropic subjects (EMMs, n = 63), subjects with late-onset myopia (LOMs, n = 50) and subjects with early onset myopia (EOMs, n = 51). Further a control experiment examined the differences between DA and bright-field accommodation (BA) conditions in a subset of subjects. All measurements of open-loop accommodation were carried out monocularly using a Canon R1 infra-red optometer in static recording mode. All myopic subjects were fully corrected using soft contact lenses.

*Results.* A significant variation ($p < 0.001$) in open-loop accommodation was found between DA and PA, but no variation in open-loop level was observed between the three refractive groups. There was no interaction between these two factors. No significant difference was found between the BA level and DA level in any of the refractive groups.

*Conclusions.* Open-loop accommodation response positions vary according to the experimental conditions employed during measurement. No refractive group differences in the open-loop response were apparent.

**Keywords:** Open-loop; *accommodation*; *myopia*; *emmetropia*

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## Introduction

When accommodation is denied negative feedback information regarding retinal image quality it adopts an intermediate resting state known as the open-loop level.[1, 2, 3] The open-loop level in darkness shows intersubject variability between 0 and 4D when measured with a laser optometer (mean value = 1.52D ± 0.77D)[1] and is known to be influenced by a number of non-optical factors including cognition,[4,5] perceived proximity,[6] refractive error,[7] pharmacological agents[8] and stress.[9]

Refractive group differences in open-loop accommodation have been studied extensively. McBrien and Millodot[7] found that LOMs have significantly lower baseline open-loop levels than either EOMs or EMMs in the dark. They suggested that the lower open-loop levels in LOMs resulted from innervational differences in the ciliary muscle. Many studies have supported their results,[5,10,11] although other studies failed to confirm these differences.[12,13,14] This lack of consensus is unsurprising because of the relatively small subject numbers used in these studies, as the intersubject variability even in the same refractive group is known to be large.[15]

A confounding factor in the measurement of open-loop accommodation is that the values attained are influenced by both the instrumentation and technique used to open-loop the accommodation system. In terms of instrumentation, laser optometer readings are generally more myopic than those found with infra-red optometers as the open-loop target within the visual field produces an additional proximal accommodative component to the open-loop measure.[16,17] Various techniques have been used to open the accommodative loop; the three most common being darkness (dark accommodation, DA),[1,18] pinhole (pinhole accommodation, PA)[1,19] and bright empty field (bright field accommodation, BA).[1,20]

Recently we investigated the open-loop response level in a large group of emmetropic subjects using these three methods[21] and found that DA and BA levels were significantly related. However, PA was only weakly related to DA and BA with a significantly higher open-loop level obtained for this viewing condition. Further manipulation of the experi-

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mental presentation demonstrated that the increase in open-loop level was due to the proximal effect of the pinhole pupil located in front of the eye.

The above findings are of interest in the context of myopia development as the prevalence of myopia has been found to be greater in near work conditions that require high levels of proximal demand. This is especially true in microscopy[22] where experimental studies have shown that instrument viewing of this type initiates an open-loop type response.[23] Particularly relevant is a recent longitudinal study investigating myopia onset and progression in 251 clinical microscopists between 21 and 63 years. Of the eyes that were emmetropic at the start of the study 39% became myopic with a mean change of –0.58D. Of the eyes that were myopic at the start of the study 48% had further progression in their myopia which averaged –0.77D. Despite each refractive group exhibiting a tendency to develop myopia when subjected to certain viewing conditions, differences were found in the level of susceptibility of each group to increased myopia development.

Currently it is uncertain what drives this variation in susceptibility to become myopic. When viewing through a microscope, subjects accommodate to a myopic level that is commonly called instrument myopia. It is possible that refractive group variations in the level of instrument myopia occur during microscope viewing and could explain the differences in susceptibility. The conditions found during microscope viewing (increased depth of focus, exit pupil position and proximity) are closely related to those experienced by subjects when viewing through a pinhole, making pinhole accommodation a useful measure in determining whether accommodative response differences exist between refractive groups.

In this experiment we measure DA and PA in a large group of subjects. Additionally, to provide a control for the DA condition we compare DA and BA measures in a subset of subjects. Evidence suggests the open-loop techniques that illuminate the retina produce accommodation adaptation aftereffects that are larger than those found in darkness.[24] Furthermore, Wolfe and O'Connell[25] found that the presence of light in open-loop conditions induced the accommodative system to maintain a more positive vigilant state. Both these studies indicate that a different response mechanism is being initiated in BA measurement in comparison to DA, a finding that contrasts with our recent results.[21]

## Materials and methods

Open-loop accommodation measurements were carried out using a Canon R1 objective infra-red optometer in its static recording mode. All subjects were young, healthy and had an astigmatic error of < 0.75D as measured on the Canon R1 optometer. Myopic subjects were corrected (best spherical refraction) using soft contact lenses (Acuvue 58% water content). Residual refractive error was accounted for during data analysis. Following optical correction each subject achieved a visual acuity of 6/6 or better. The refractive classification of each subject was determined by initial age of myopic correction. EOMs were defined as subjects who were corrected initially for myopia before the age of fifteen years with LOMs initial correction being fifteen years or later.[7, 26] EMMs had refractive errors ranging from –0.25D and +0.50D. Subjects were classified myopic if the refractive error was greater or equal to –0.50D.

In all experiments subjects were required to sit in complete darkness for 5 minutes prior to data collection in order to dissipate the effects of any previous visual stimulation.[18] Presentation of each condition was randomised with subjects being allowed to adapt to each viewing condition for 2 minutes prior to data collection to allow the open-loop level to stabilise.[27] A minimum of 20 sphero-cylindrical readings were taken from the left eye of each subject over a 2 minute time period, and the average taken of the best sphere of each measure. Cylinder measures larger than 0.75D were excluded.

The experiments were conducted using the same subject sampling, protocols and instrumentation at the Department of Vision Sciences, Glasgow Caledonian University and at School of Life and Health Sciences at Aston University. The two laboratories had similar sizes and surrounding, thereby minimising any differences in the effect of surround propinquity[28] between experiments. The research procedures carried out at both laboratories followed the tenets of the Declaration of Helsinki.

### Measurement of DA and PA levels in three refractive groups

One hundred and sixty four subjects (63 EMMs, 51 EOMs and 50 LOMs) participated in this part of the study. Subject details for each refractive group are shown in Table 1. The accommodative loop was opened using DA and PA. In the DA condition subjects were instructed to look straight ahead into the darkness. In the PA condition subjects viewed one letter in a line of N8, high contrast print (90%) under photopic conditions (40 cd/m$^2$) in a Badal system at a vergence of 0D, through a 0.5 mm artificial pupil punched in an IR filter (Kodak Wratten 87). It has been shown previously that a 0.5 mm pinhole pupil is required to ensure the accommodation system becomes fully open-loop.[29]

### Measurement of DA and BA in three refractive groups

The subject group consisted of 60 subjects (20 EMMs, 20 EOMs and 20 LOMs). Subject details for each refractive group are shown in Table 2. The accommodative loop was opened using: 1) DA and 2) BA. DA conditions were the same as employed in part 1. BA conditions were imposed by illuminating a diffusing screen (space-averaged luminance 200 cdm$^{-2}$) which filled the whole field of view at approximately 20cm in front of the observer.

*Table 1.* Subject details for experiment 1: Measurement of DA and PA in three refractive groups.

| Subjects | EMMs (n = 63) | LOMs (n = 50) | EOMs (n = 51) |
|---|---|---|---|
| Age (years) | 20.7 ± 2.8 | 22.1 ± 4.4 | 21.0 ± 3.8 |
| Mean best sphere refraction (DS) | +0.08 ± 0.27 | –1.66 ± 0.76 | –3.43 ± 2.01 |

*Table 2.* Subject details for experiment 2: Measurement of DA and BA in three refractive groups.

| Subjects | EMMs (n = 20) | LOMs (n = 20) | EOMs (n = 20) |
|---|---|---|---|
| Age (years) | 21.9 ± 0.6 | 22.6 ± 0.8 | 22.0 ± 0.9 |
| Mean best sphere refraction (DS) | +0.04 ± 0.20 | –1.79 ± 0.65 | –3.13 ± 1.42 |

## Results

### Measurement of DA and PA levels in three refractive groups

The mean values for each refractive group in the two open loop conditions employed are shown in Figure 1. The main feature of the data is that PA values are increased in comparison to DA values in all three refractive groups. Two factor ANOVA for the grouped data revealed no significant variation in open-loop level between the three refractive groups ($p = 0.233$) but variation in open-loop level between the PA and DA methods was significant ($p < 0.001$). There was no significant interaction between these two factors ($p = 0.132$).

### Measurement of DA and BA in three refractive groups

The mean value for DA and BA measurements for each refractive group is shown in Figure 2. A two-way ANOVA was computed to assess the data: both refractive error ($p > 0.05$) and method of opening the loop ($p > 0.05$) did not significantly affect open-loop levels. Correlation analysis between open-loop values revealed a significant correlation between DA and BA for all three refractive groups (Table 3).

## Discussion

The results agree with our previous finding that the method employed when opening the accommodation loop can influence the values obtained.[21] In the present experiment positive shifts in open-loop level were measured in PA in comparison to DA in all three refractive groups (Fig. 1). This suggests that DA and PA methods of measurement are fundamentally different. In DA conditions, the *stimulus* is degraded to eliminate the influence of blur on the accommodative response, whereas in PA conditions, it is the *subject's response* to the stimulus that is reduced by increasing the depth-of-focus to such an extent that blurring of the target is not detected. In addition, the physical presence of the target and artificial pupil in the PA measures may induce proximal accommodation and stimulate mental effort in processing the contents of the target.

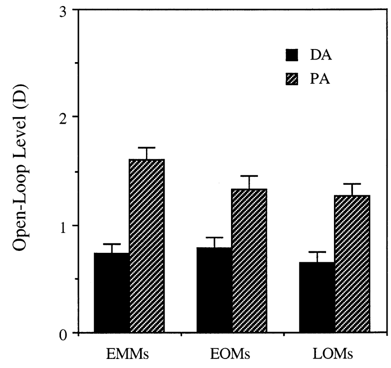


*Figure 1.* The mean open-loop levels for each of the three refractive groups (EMMs, LOMs, EOMs) in DA and PA conditions. Error bars indicate ± SEM.

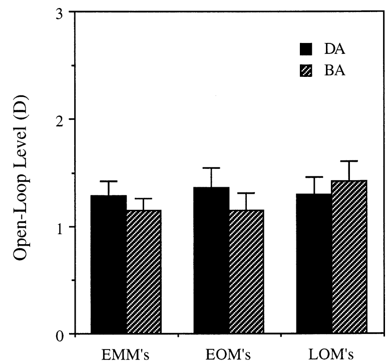


*Figure 2.* Mean open-loop response levels for EMMs (n = 20), LOMs (n = 20) and EOMs (n = 20) in DA and BA experimental conditions. Error bars indicate ± SEM.

*Table 3.* Correlation of BA and DA values in all three refractive groups.

| DA v BA | Correlation | F-value | Significance |
|---|---|---|---|
| EMMs | 0.83 | 39.91 | p = 0.0001 |
| EOMs | 0.465 | 4.956 | p = 0.039 |
| LOMs | 0.798 | 31.494 | p = 0.0001 |

Our results indicate that the DA and PA measures are not equivalent and suggest that the accommodation system does not simply rest at its open-loop level when the appropriate conditions are imposed, instead many factors both psychological and physiological contribute to the level of accommodation response. PA measures produced an increased accommodation response of similar magnitude in all three refractive groups. In terms of microscopists it seems unlikely that variations in the accommodation level initiated by viewing through a microscope increase susceptibility to myopia development. Other factors must be involved in making myopes more susceptible to increased axial elongation, the contributory factor in the development of myopia.

Our results do not agree with a number of studies that have suggested that LOMs have a lower DA response. In both experiments a large individual variation in open-loop response value was found in all observers regardless of refractive status and method of measurement. This large individual variability makes investigating refractive error differences difficult (especially with smaller subject numbers) and could explain the lack of consensus between authors on this issue. Another possible explanation for the conflicting results is that the refractive classification should be made according to the stability of myopia instead of age of onset. Supporting evidence for this theory is provided by two studies that have shown changes in DA level occur concurrently with the development of refractive error when measured on a longitudinal basis.[30,31]

No differences were found between DA and BA conditions in all refractive groups suggesting that these methods of measuring open-loop accommodation produce similar results. This result differs from the study of Wolfe and O'Connell[25] who found, using a Scheiner principle vernier optometer, subjects adopted a more positive vigilant state when the retina was illuminated. Higher BA levels have also been found in children although the difference seems to be age-related, only occurring in the younger age groups studied (6–8 years age range).[32]

In conclusion, the pinhole method of opening initiates a higher level of open-loop response in comparison to dark and bright field accommodation. No significant differences in the accommodation response were found between the different refractive groups in all three methods of opening the loop. In microscopists, susceptibility to myopia development is not related to variations in the accommodation response during microscope viewing.

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