Adaptation of the Resting States of Accommodation

Dark and Light Field Measures

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Without an adequate stimulus to focus, the eyes accommodate for a "resting state" that averages about 1.6 diopter (D) (62 cm). The resting state can be made more "myopic" by adaptation to a near accommodative or vergence stimulus. In the present experiment, 21 subjects were tested for adaptation to both types of stimuli. Resting state was measured before and after adaptation in the dark (dark focus) and in the presence of an illuminated empty field. The authors found that (1) preadaptation resting states were more myopic in the light field than in the dark test conditions; (2) accommodative and vergence stimuli produce myopic shifts in dark and light field resting states; and (3) a subset of the subjects show much larger aftereffects in the light field conditions. These subjects also show the largest difference between preadaptation dark- and light-field measures. Differences between dark- and light-field measures of resting state in these and other experiments may require a re-examination of the hypothesis that there is a single resting state for each subject. Invest Ophthalmol Vis Sci 28:992-996, 1987

In the absence of appropriate stimuli to focus, the accommodative system rests in a position somewhere between its near and far points. This "resting state" is idiosyncratic but averages about 1.5–1.7 diopter (D) (58–67 cm). The resting state can be measured with a variety of methods, and agreement among those methods is generally quite good. In particular, measurements made while subjects view an empty but illuminated field are reported to agree well with measurements taken while subjects are in the dark. The resting state may represent a balance between input to accommodation from the sympathetic and parasympathetic branches of the autonomic nervous system.

With normal conditions of visual stimulation, the resting state is relatively stable over the short term. It is subject to change, however. Owens and Wolf found that 1 hr of reading at a near distance could move the dark focus to a more myopic position. Schor et al. found similar changes with much briefer periods of adaptation and smaller (eg, 1 D) magnitude adapting stimuli. Further, these changes could be produced by exposure to a vergence stimulus. Presumably, vergence accommodation secondary to the vergence acted as the adapting stimulus. These changes in resting state were measured when accommodative loop was opened by using a small artificial pupil to increase depth of field or by simply removing the accommodative stimulus and replacing it with a blank field. For example, a subject might adapt for 1 min to a 2 D target. In the depth of field version, at the end of a minute, a small virtual pupil would be placed in front of the subject's normal pupil. This rendered accommodation unnecessary because the stimulus would now be in focus regardless of the accommodative status of the eye. Schor et al then measured the time required for the eye to return to its resting state. This lag in recovery or "aftereffect" could last several minutes after as little as a minute of adaptation.

If the stimulus was turned off and accommodation was measured in the dark after adaptation, no aftereffect was seen. The aftereffect could be reinstated by turning the lights on. This is somewhat puzzling because Owens and Wolf found measurable adaptation with resting state measures taken in the dark. Owens and Wolf did not measure adaptation of the resting focus with illuminated blank fields.

In the present experiment, we have measured aftereffects of accommodation following adaptation to accommodative and vergence stimuli at near distances. We find, in agreement with Schor et al, that exposure to either accommodative or vergence stimuli produces aftereffects. On average, those aftereffects are larger when measured with an illuminated field than in the dark. However, in agreement with
Owens and Wolf, we find that reliable aftereffects can be measured in the dark. Finally, in our subject population, pre-adaptation measures of resting state are significantly more myopic when measured in an illuminated field than when measured in the dark.

Materials and Methods

Apparatus and Stimuli

Accommodation was measured with a vernier optometer based on the Scheiner principle and described in detail elsewhere. All measurements were made with the right eye. Stimuli were viewed in standard Maxwellian view optics. The field was circular with a blurred edge formed by a field stop placed at 16 D, well in front of the near point of accommodation. This edge, therefore, was not an accommodative stimulus. The field subtended about 7 deg. In the absence of an accommodative stimulus, the illuminated blank field had no texture and no contours except the blurred border formed by the field stop. The adapting stimulus for accommodation was a square 6.6 deg on a side. It contained thin (6 min), high-contrast (>90%), black vertical lines separated by 27 min (1.8 cpd). The stimulus was viewed at an optical distance of 20 cm (5 D) and was presented only to the right eye. The optometer target was flashed for 125 msec. This is too brief a time to initiate an accommodative response, although it does introduce some light into the dark-field test condition.

The adapting stimuli for convergence consisted of two dim, red light-emitting diodes (LEDs), each subtending 8 min. Each eye viewed one LED. They were placed so that they would be fused when the eyes were converged for a distance of about 14 cm (with variation resulting from differences in interpupillary distance). Small fixation points are not accommodative stimuli. In a control experiment, we confirmed this finding for our red LEDs. Change in the optical distance of a single red spot was not systematically correlated with accommodative status. While viewing a single red spot, accommodation remained at its resting state.

Methods

Two sessions were run for each subject: one for adaptation to the accommodative stimulus, one for the convergence stimulus. Sessions were at least 1 day apart. At the start of each session, resting focus was measured in two test conditions: (1) with the light field on and (2) in the dark. Three measures were taken in each condition. The subject then viewed the adapting stimulus for 5 min. During adaptation, accommodation was measured several times to assure that the subject was indeed accommodating. After adaptation, three more measures were taken in each of the two test conditions. Order of sessions (accommodative or vergence adaptation first) and of testing (dark or light field first) was random across subjects. Post-adaptation measures were taken within 90 sec of the end of adaptation.

Subjects

Twenty-one subjects were tested in each condition. Ages ranged from 18–31 yr. Nineteen were not informed about the methods and purpose of the experiment. The authors served as the other two subjects. All subjects wore their normal correction for best acuity during the experiment. All subjects gave informed consent for their participation. The experiment was approved by the Massachusetts Institute of Technology (MIT) Committee on the Use of Humans as Experimental Subjects.

Results

Initial Resting State Measures

Figure 1 shows the resting states measured in the dark and with a 7-deg, illuminated blank field. Two sets of 21 measures exist because baselines were measured before each of the two sessions (accommoda-
tested during the course of a normal weekday. It is unlikely that 19 of 21 of them had engaged in prolonged near work immediately before the experiment.

**Accommodative Adaptation Measures**

During adaptation to accommodative stimuli, the average position of accommodation across subjects was 4.11 D. Figure 2A shows changes in resting state following adaptation to an accommodative stimulus. Significant differences between preadaptation and postadaptation measures of resting state were found with both dark- and light-field measures. The change from baseline was 0.18 D for the dark field (t = 2.45, df = 20, P < 0.05) and 0.60 D for the light field (t = 2.80, P < 0.05). The difference between dark- and light-field adaptation was also significant (difference = 0.43, t = 2.24, P < 0.05).

**Convergence Adaptation Measures**

During adaptation to the convergence stimuli, the average accommodative position of subjects was greater than 4.6 D. Figure 2B shows changes in resting state following adaptation to the convergence stimulus. Again, significant differences between preadaptation and postadaptation measures of resting state were found with both dark- and light-field measures. The change from baseline was 0.22 D for the dark field (t = 2.25, P < 0.05) and 0.81 D for the light field (t = 2.82, P < 0.05). The difference between dark- and light-field adaptation was suggestive but just failed to reach statistical significance (difference = 0.60, t = 2.00, P = 0.058).

**Differences Between Dark- and Light-Field Test Conditions**

Looking at Figure 2, it is clear that a few subjects show far more adaptation when tested with a light field than in the dark. Four subjects showed more than a 2.5-D difference between dark- and light-field measures of resting state after both forms of adaptation. One more subject showed a large difference only after the accommodative adaptation. On closer examination, the average differences between dark- and light-field postadaptation measures seen due entirely to these subjects. This is in contrast to the light-dark differences in preadaptation conditions in which virtually all subjects show more myopic resting states in the light. After adaptation, larger light-field after-effects were found for 13 of 21 subjects in the accommodation condition (Fig. 2A) and 11 of 21 subjects in the convergence condition (Fig. 2B). Neither of these splits is significant (chi-square values, 1.8 and 0.2, respectively).
The five subjects who show much more adaptation in the light behave in a qualitatively different manner from the other subjects. After adaptation, they appear to be in a form of accommodative spasm in the light. When measured in light field conditions, their postadaptation resting states were more myopic than the maximum measured in the apparatus (4.8 D). These subjects also showed greater differences between dark- and light-field measures of resting focus before adaptation. For these five subjects, the difference between dark- and light-field measures before adaptation averaged 1.0 D and 1.2 D for the two sets of preadaptation measures (Fig. 1). The remaining 16 subjects showed average differences of 0.3 D and 0.4 D for the two baseline sets. For both baseline sets, the "superadaptors" differ significantly from the other subjects (t = 3.1, df = 19, P < 0.01 for both sets of baseline measures). Using light-field measures of resting focus, Schor and Tuetaki also report that some subjects are much more adaptable than others.

Discussion

Dark- and Light-Field Baselines

The difference between baseline measures of dark- and light-field resting states before adaptation is puzzling given previously published data indicating that no reliable differences exist. Could our results be due to a few aberrant subjects? This seems unlikely. As noted in the preceding section, there appear to be two groups of subjects. The superadaptor group shows large light−dark differences between preadaptation measures and very large light−dark differences after adaptation. However, even if these subjects are removed from consideration, about 90% of the remaining subjects have resting states that are more myopic when measured in the light.

A second possibility is that there is some systematic difference between this population sample and that of Leibowitz and Owens. Given that some subjects show more adaptation with light fields than with dark ones, our more myopic light-field baseline measures of resting state suggest that our subjects were already adapted to something when they came into the laboratory. Owens and Harris have found that college students exhibit a progressive "myopization" of the dark focus during freshman year and have hypothesized that the near work of studying is the cause. Other forms of near work also have been suggested as possible causes of myopia in adults. It is possible that our subjects were preadapted by the rigors of an MIT education.

There are two problems with this account. First, as noted above, only a subset of our subjects show more adaptation in the light than in the dark (although all of the subjects studied by Schor et al show this difference). If these superadaptors are, indeed, a special set of subjects, we need a different explanation for the more myopic dark focus measures in the remainder of the population. Second, if our subjects are preadapted by MIT why weren't the undergraduates in the Leibowitz and Owens studies similarly preadapted? It seems improbable to assume that the visual stimuli attendant on an MIT education are significantly different from those found at Penn State.

Finally, it could be proposed that subjects "expect" an accommodative stimulus to be present in the light-field condition but not in the dark one. For this account to explain the difference between light- and dark-field resting states, we would need to assume either that subjects systematically expect stimuli closer than their dark focus or that the state of expectation, in and of itself, causes a myopic shift. The latter is equivalent to proposing that there are different resting states for light- and dark-field conditions.

Adaptation Results

In agreement with Schor et al, our data show that the resting state of accommodation can be adapted by exposure to either accommodative or convergence stimuli. This is further support for Schor's model in which the input of convergence accommodation to the accommodative pathway is placed before the site of adaptation.

Our results do not agree with the conclusion of Schor et al that adaptation is entirely masked in darkness. Although our superadaptors show a marked reduction in adaptation magnitude when the lights are out, we find significant adaptation in dark-field conditions for those subjects and for the rest of the subjects. Here our results are consistent with those of Owens and Wolf who also find adaptation under dark-field conditions. Schor and coworkers' studies use fairly weak adapting stimuli (eg, 1D for 1–2 min) compared with those used here or in the Owens and Wolf study (3–5 D for 5 or more min). The resulting aftereffects are often quite brief. Perhaps changes in the dark-field measures of resting state are found only if very strong adapting stimuli are used.

Another difference between this study and that of Schor et al is the technique of measurement. The vernier optometer does introduce brief (125 msec) flashes of light into the dark field. These flashes are thought not to stimulate an accommodative response, but it is possible that they weakly mimic the effects of an illuminated field and thus produce weak evidence for adaptation where none was seen before. This account, however, does not explain why the
light-dark differences after adaptation are seen for only the superadaptor subset of the population.

Two substantive issues are raised by the data on adaptation of the resting state of accommodation. First, what accounts for the apparent qualitative differences in adaptation between normal and superadaptor subjects? It would be interesting to know if superadaptor status is related to other visual functions (eg, accommodative convergence/accommodation ratios\(^{20}\)). Do superadaptors show more adaptation in other paradigms (eg, visual aftereffects)? Are they more or less susceptible to progressive changes in refraction (eg, late-onset myopia)?

The second issue involves the difference between dark- and light-field measures of resting focus. Why do these differences occur? Perhaps it is incorrect to speak of both of these measures as resting states. Perhaps the accommodative system rests only in the dark and maintains a more vigilant state when any light is present. Such an arrangement would be practical. In the dark, there is no possibility of a stimulus for accommodation. In the light, it is always possible that a stimulus is present in the field of view but is so far out of focus that it is invisible.

**Key words:** accommodation, adaptation, aftereffect, resting state, dark focus

**References**