The attentional blink in amblyopia

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Amblyopia is a disorder of visual acuity in one eye, thought to arise from suppression by the other eye during development of the visual cortex. In the attentional blink, the second of two targets (T2) in a Rapid Serial Visual Presentation (RSVP) stream is difficult to detect and identify when it appears shortly but not immediately after the first target (T1). We investigated the attentional blink seen through amblyopic eyes and found that it was less finely tuned in time than when the 12 amblyopic observers viewed the stimuli with their preferred eyes. T2 performance was slightly better through amblyopic eyes two frames after T1 but worse one frame after T1. Previously (A. V. Popple & D. M. Levi, 2007), we showed that when the targets were red letters in a stream of gray letters (or vice versa), normal observers frequently confused T2 with the letters before and after it (neighbor errors). Observers viewing through their amblyopic eyes made significantly fewer neighbor errors and more T2 responses consisting of letters that were never presented. In normal observers, T1 (on the rare occasions when it was reported incorrectly) was often confused with the letter immediately after it. Viewing through their amblyopic eyes, observers with amblyopia made more responses to the letter immediately before T1. These results suggest that childhood suppression of the input from amblyopic eyes disrupts attentive processing. We hypothesize reduced connectivity between monocularly tuned lower visual areas, subcortical structures that drive foveal attention, and more frontal regions of the brain responsible for letter recognition and working memory. Perhaps when viewing through their ambylopic eyes, the observers were still processing the letter identity of a prior distractor when the color flash associated with the target was detected. After T1, unfocused temporal attention may have bound together erroneously the features of succeeding letters, resulting in the appearance of letters that were not actually presented. These findings highlight the role of early (monocular) visual processes in modulating the attentional blink, as well as the role of attention in amblyopic visual deficits.

Keywords: attention, amblyopia, visual working memory


Introduction

In normal visual development, binocular receptive fields form as a result of the similar stimulation received from the two eyes. In amblyopia, this process is disrupted because of a mismatch between the two eyes’ images, which normally grow sharper during the first few years of life with the development of orientation sensitivity at fine spatial scales. Amblyopia is impairment in visual acuity in one eye, thought to result from the cortical suppression of the inputs from that eye (Ciuffreda, Levi & Selenow, 1991). Responses in the lateral geniculate nuclei (LGN), the parts of the thalamus that first receive the neural inputs from the two eyes, are not affected by amblyopia, so we must look further along the visual processing stream to find where amblyopic eyes are suppressed. The anatomy of ocular dominance columns in primary visual cortex (V1) is unaffected by developmental amblyopia in humans when its onset is after age 2 years (Horton & Hocking, 1996), but there is evidence based on functional MRI for the shrinkage of ocular dominance columns in amblyopia of earlier onset (Goodyear, Nico, & Menon, 2002). In addition, fewer binocular receptive fields develop or are maintained during development in amblyopia, and instead the foveal image communicated from V1 to higher visual areas relies predominantly on information from the unimpaired eye, based on the psychophysical finding that contrast sensitivity does not sum effectively between the two eyes in amblyopia (McKee, Levi, & Movshon, 2003). Little is known about the mechanisms by which the brain suppresses the input from the ambylopic eye, both during development and in the maintenance of single vision in amblyopic adults who lack binocular fusion. One possibility is that it is similar to the normal suppression of one eye’s input during binocular rivalry. When different images are presented dichoptically to the two eyes, for example a red horizontal grating in the left eye and a green vertical grating in the right eye, the perception is one of a periodic alternation between the two images every few seconds (Blake & Fox, 1974). If one of the images is brighter or sharper, as may be the case in amblyopia, that image will predominate (Smith, Levi, Manny, Harwerth, & White, 1985). Therefore perhaps the degradation of acuity in the ambylopic eye serves to facilitate its suppression, resulting in less effortless single vision (Holopigian, Blake, & Greenwald, 1988). On the other hand, there may also be a more active mechanism by
which visual attention selectively enhances the input from the dominant eye, or a relative impoverishment of the amblyopic eye's ability to attract attention by means of pre-attentive bottom-up salience mechanisms. Indeed, on the basis of an EEG study, Van Balen and Henkes (1962) suggested that the amblyopic visual system may be “inattentive” when viewing with the amblyopic eye.

The time course of attention in normal vision has been studied using the attentional blink paradigm. When two targets are presented in rapid succession, using RSVP, the second target (T2) is difficult to detect and identify when it is presented soon (200–500 ms) but not immediately (100 ms) after the first target (Raymond, Shapiro, & Arnell, 1992). We have shown that when targets and distractors are all letters, this is because after the first target (T1), distractors presented around the time of T2 are likely to enter visual working memory in its place (Popple & Levi, 2007), perhaps as a result of failure to disengage attentional enhancement (Bowman & Wyble, 2007).

In the present experiment, we studied the time course of attention in amblyopia. Others have found effects of amblyopia on the size required for the identification of a single target number presented in an RSVP stream (Bonneh, Sagi, & Polat, 2007) but only a small effect on the duration of the attentional blink in amblyopia (Asper, Crewther, & Crewther, 2003). Our method was more sensitive because it enabled us to compare not only the performance of the two eyes but also the pattern of errors, in order to see which distractors entered working memory in place of T1 and T2.

Methods

Subjects

Twelve observers with normal or corrected-to-normal visual acuity, and twelve observers with amblyopia (defined as a 2-line or greater difference in visual acuity between the two eyes) participated in this study. The ages of the normal observers ranged from 18 to 36, and five were male. The ages of the amblyopic participants ranged from 15 to 40. Three of the observers had anisometric amblyopia, three had both anisometropia and strabismus, and six had strabismic amblyopia without significant anisometropia. Four of the amblyopic observers were male. Best corrected visual acuity in the amblyopic eyes ranged from about 20/30 to 20/200, and the distribution of acuities can be gleaned from the inspection of Figure 7 in the Results section, which shows results as a function of depth of amblyopia.

Apparatus and stimuli

The stimuli were 40-point Times font letters displayed using Presentation (Neurobehavioral Systems, www.neurobs.com) on a Dell Inspiron 9100 laptop with LCD screen set at 1024 × 768 pixel (32 bit color) resolution, using a frame rate of 60 Hz. The screen was viewed from about 50 cm, such that letters subtended about 1.5° of visual angle and were highly visible. In most cases, stimulus size was doubled for amblyopic viewing, to ensure that performance was not limited by visual acuity. The recorded stimulus duration on the computer was 33–34 ms, although LCD persistence may have in fact lengthened the stimuli somewhat.

Stimuli were uppercase letters in Times New Roman font presented in ‘Red’ (CIE1931 x = 0.60, y = 0.33, lum = 16.75 cd m–2) or ‘Gray’ (CIE1931 x = 0.27, y = 0.32, lum = 16.15 cd m–2) on a black (near zero luminance) background (the International Commission on Illumination (CIE) adopted the XYZ definition of color space in 1931, http://en.wikipedia.org/wiki/CIE_1931_color_space). Note that both colors have almost identical luminance and vary only in their chromaticity. Stimuli were presented at a rate of 10 Hz (Stimulus Onset Interval SOA = 100 ms).

Design

We used a 2 × 7 within-subjects factorial design and varied: 1) The eye tested (amblyopic or preferred eye) and 2) The number of frames between the two targets (1, 2, 3, 4, 5, 6, or 7 frames). The color of the targets (red from gray or vice versa) was also varied, but because not all participants completed the same number of blocks with each color the data were collapsed across these two conditions.

We measured performance, as is customary in the Attentional Blink literature (percent correct T2 report, out of those trials in which T1 was identified correctly and reported as either the first or the second response). We also measured the number of confusion errors for the first and second responses, as a function of distance from T1 and T2, and the number of non-stimulus errors (report of letters not presented).

Procedure

Letters were selected randomly from the full 26-letter English alphabet, without replacement, so that we could look at the positional errors within each trial. Each trial was preceded by an ‘X’ fixation marker and was initiated by pressing the space bar. The task was to identify and type in the two target letters at the end of the trial. Participants had an option to repeat a trial at will if they made a typing error, in which case that trial was not recorded and a replacement trial was generated. Figure 1 shows a schematic illustration of a trial.

Each trial consisted of 14 frames. The first target could appear on one of frames 3 to 6 at random, and the second
target arbitrarily 1 to 7 frames later. This means that there were always at least 2 distractor frames after T2. Trials were blocked according to target color, in blocks of 70 trials in which each of the 7 possible frame delays between the two targets was presented 10 times. Subjects completed 3–6 blocks in each eye.

Amblyopic observers viewed the stimuli monocularly and repeated the same number of blocks with each eye, alternating between the amblyopic and preferred eyes on different sessions or days. The control group with normal vision in both eyes viewed the stimuli binocularly.

As a control, one normal observer viewed the stimuli monocularly, and with the double-sized letters. There were no significant differences in performance between the two eyes, or between the 1.5° and 3° letters (see Appendix A).

**Results**

**Task performance**

The results (Figure 2) indicate differences between Amblyopic and Preferred eyes, in the shape of the attentional blink curve—the proportion of correct T2 responses (conditioned on correct T1 report and regardless of the order in which the responses to the two targets were given) as a function of Time After T1. ANOVA was used to determine the chance probability of the obtained data in a repeated-measures (within-subjects) analysis, using \( p < 0.05 \) as the threshold for the significance of any effects found. The interaction between Eye and Time After T1 was statistically significant with \( F(6,66) = 4.063, p = 0.002 \). A Simple Contrast showed this was due to a smaller difference between 200 and 700 ms (lag 2 or 7 frames) after T1 in the Amblyopic Eyes than in the Preferred Eyes (\( F(1,11) = 8.094; p = 0.016 \)), suggesting that the attentional blink is shallower in amblyopia.

![Figure 1. Sample trial, showing stimuli and procedure. In this example, the targets were 'F' and 'C' but the response was 'F' and 'N,' which is a correct report of T1 but a positional error of −1 for T2, as 'N' was the letter immediately preceding T2.](image1)

![Figure 2. Performance (probability of correct T2 report, regardless of order, given correct report of T1) as a function of time after T1 and eye. Means across the 12 amblyopic observers are shown. Error bars shows 95% confidence intervals.](image2)
Preferred Eyes were significantly better than Amblyopic Eyes at identifying T2 100 ms after T1 \((t(11) = 2.526; \ p(2\text{-tailed}) = 0.028\)\). Amblyopic Eyes were significantly better than Preferred Eyes at identifying T2 200 ms after T1 \((t(11) = 2.789; \ p(2\text{-tailed}) = 0.018\)\). The difference 700 ms after T1 was not significant, suggesting that the targets were more or less equally visible. The overall effect of Eye across all the different lags was not significant.

The effect of Time After T1 was highly significant, confirming the presence of an attentional blink \((F(6,66) = 39.289, \ p < 0.001\)\). This was so also within the Amblyopic Eyes, despite the shallower attentional blink in this condition \((F(6,72) = 18.120; \ p < 0.001\)\).

When the order of the responses was taken into account (Figure 3), Time After T1 also had a significant effect on T1 performance, in both preferred and amblyopic eyes \((F(6,66) = 16.220; \ p < 0.001\)\), as a result of errors made when T2 lagged T1 by 100 ms \((F(1,11) = 25.578; \ p < 0.001\)\) and there was a small effect of Eye on T1 performance \((F(6,66) = 6.635; \ p = 0.026\)\).

Comparing the Preferred Eyes of the Amblyopic Group, and the performance of the Control Group, no significant differences were found, nor was there a significant interaction between Group and Time After T1 (Figure 4).

**Error distributions**

The distribution of errors (measured by taking response order into account) was markedly different in Amblyopic Eyes, compared with Preferred Eyes, as can be seen from the inspection of Figure 5. While viewing with their Amblyopic Eyes, participants were likelier to report the distractor preceding T1 \((F(1,11) = 19.054; \ p = 0.001\)\), regardless of Time After T1. In a comparison between T1 and T2, looking at errors consisting of reporting the preceding distractor, the interaction between Target and Eye was significant \((F(1,11) = 10.284; \ p = 0.008\)\), consistent with the finding of no significant effect of Eye on responses to the distractor preceding T2. In Amblyopic Eyes, there was a tendency to report the distractor preceding T1 but not T2.

Responses to non-stimulus letters (those that were not part of the 14-letter sequence—shown by the histograms at the extreme right in Figure 5) were more frequent in Amblyopic Eyes than in Preferred Eyes, significantly so as responses to T2 \((F(1,11) = 16.184; \ p = 0.002\)\) and with a smaller effect on T1 \((F(1,11) = 6.059; \ p = 0.027\)\). The interaction between Eye and Target was significant \((F(1,11) = 11.565; \ p = 0.006\)\). In Amblyopic Eyes, there was a tendency to report a non-stimulus letter in place of T2, but less so with T1.

In Preferred Eyes, as compared with Amblyopic Eyes, responses were more frequently to the distractor immediately after T2 \((F(1,11) = 14.095; \ p < 0.003\)\) or immediately after T1 \((F(1,11) = 6.671; \ p = 0.025\)\). This effect was significantly stronger in regard to T1 \((F(1,11) = 19.859; \ p = 0.001\)\). The distribution of errors in the Preferred Eyes of Amblyopic Group was not found to differ significantly from that in the Control Group.
Following Popple and Levi (2007), we analyzed the probability of reporting the targets or their neighbors in time (Figure 6). For T1 and the three letters immediately before it, there was no longer a significant effect of amblyopia, but there was still an effect of lag ($F(6,66) = 19.398; p < 0.001$). For T2 and the three letters before and after it, there was no longer an effect of lag, however there was an effect of amblyopia ($F(1,11) = 13.801; p = 0.003$). The finding that, in both these cases, one effect at least was significant suggests that these results were not due to ceiling effects from the approximation procedure.

### Effects of amblyopia depth and type

The greater the depth of amblyopia, the smaller was the attentional blink in the amblyopic eye, as compared with the preferred eye (estimated here by the difference in performance between lags of 7 and 2 frames after T1 and obtaining the ratio of this measure in the amblyopic eye to that in the preferred eye; Figure 7). There was a significant correlation between depth of amblyopia and attentional blink depth ratio ($R^2 = 0.618; F(1,11) = 16.149; p = 0.002$),

Figure 5. Histograms showing the average probabilities of responses as a function of temporal position in relation to T1 and T2. The upper panel shows T1 responses, and the lower panel shows responses to T2. Responses were averaged across observers and conditions. Negative numbers on the x-axis imply responses to frames that preceded the target frame. ND indicates responses to a non-distractor letter. Error bars indicate 95% confidence intervals.

Figure 6. Effects of amblyopia on ‘approximate’ T1 (upper panel) and T2 (lower panel) performances, measured as correct responses to T1 or responses to one of the 3 letters preceding T1, and as responses to T2 or one of the 3 letters before/after it. Obtaining the ratio of this measure in the amblyopic eye to that in the preferred eye; Figure 7. There was a significant correlation between depth of amblyopia and attentional blink depth ratio ($R^2 = 0.618; F(1,11) = 16.149; p = 0.002$),

Figure 7. Attentional Blink Depth (difference between performance measured 200 and 700 ms after T1) as a ratio between Amblyopic and Preferred eyes, plotted as a function of Amblyopia Depth (difference in LogMar acuity between amblyopic and Preferred eyes).
with no evident effect of type of amblyopia (strabismic, anisometropic, or mixed).

**Summary of results**

Amblyopic vision was characterized by frequent erroneous reports of the distractor preceding T1, more responses to non-stimulus letters in place of T2, and fewer responses to the distractors immediately after T1 or T2. The attentional blink curve was shallower, with fewer correct responses (conditioned by correct T1 report) 100 ms after T1 (less ‘Lag 1 sparing’—the finding whereby the first frame after T1 is ‘spared’ from the effects of the attentional blink) and more correct responses 200 ms after T1. On average, across the different lags, T2 performance was as good (measured by percent correct) in amblyopic eyes as it was in the preferred eyes of amblyopes, but T1 performance was significantly worse in amblyopic eyes.

**Discussion**

We found that the time course of attention in the amblyopic fovea differed significantly from that obtained when the same observers viewed the stimuli with their preferred eyes. Specifically, when viewing with their amblyopic eyes, observers had a shallower ‘attentional blink,’ with less Lag 1 sparing and greater accuracy of T2 report 200 ms after T1, as a result of making fewer neighbor errors and more errors consisting of letters that were not presented in the sequence. The question is whether these differences arise from changes in the quality or function of attention, when viewing through amblyopic eyes, or changes in the quality of the image, perhaps as a result of masking. Intriguingly, responses to T1 presented to the amblyopic eye were significantly less accurate than responses from the preferred eye, and this difference resulted entirely from misreporting preceding letters in place of T1. This latter finding implicates changes in attentional processing and specifically temporal binding in amblyopia. Nevertheless, in the discussion that follows, we first consider the possibility that differences in T2 report resulted from impaired image quality in amblyopic eyes.

Vision in the amblyopic fovea is degraded, as compared with the normal fovea, both in terms of single-letter acuity and vulnerability to crowding by nearby stimuli. However, even normal observers experience considerable crowding (and reduced acuity) when stimuli are presented outside the fovea, and therefore the normal periphery has frequently been considered a model for amblyopic vision (e.g., Levi & Klein, 1985). What is the attentional blink like in normal peripheral vision? Kristjánsson and Nakayama (2002) studied the effects of spatial separation on the attentional blink, and therefore had to place their stimuli outside the fovea. They found no Lag 1 sparing, for stimuli presented at 6 deg eccentricity and with a 140 ms SOA. It is possible that this characteristic of amblyopic performance is the result of degraded vision, similar in the amblyopic fovea to the normal periphery. However, this speculation must be treated with caution, because it is not at all clear that, even in the normal fovea, Lag 1 sparing would be as pronounced at such a long SOA (Popple & Levi, 2007) and see solid circles in Figure A1, Appendix A. Additionally, although targets in Kristjánsson and Nakayama’s (2002) study were marked by a luminance cue, they were primarily distinguished from non-targets by virtue of being digits among letters, and results in this task may differ from the task in the present study. Further experiments need to be carried out to directly compare the amblyopic fovea and the normal periphery in identical attentional blink tasks.

Bowman and Wyble (2007) recently proposed a new and comprehensive theory of encoding RSVP targets in visual working memory. Their theory brings together several previous models and ideas, particularly those relating to the attentional blink. The theory has two stages:

1. a perceptual stage, in which many ‘types’ or object representations become activated in a parallel fashion, depending on their presence in the environment, and the task-dependent operations of a ‘salience filter;’

2. an encoding stage, when a series of time-labeled ‘tokens’ are bound to the activation of the salience-filtered ‘types.’

This ‘tokenization’ requires the action of a ‘temporary attentional enhancement’ (TAE) mechanism that selectively enhances the activation of salient ‘types,’ so that they can be bound to ‘tokens’ in the ‘binding pool.’ According to this theory, in the attentional blink the TAE is still suppressed by the processing of the first target when the second one arrives.

We have argued elsewhere (Popple & Levi, 2007) that Bowman and Wyble’s (2007) theory is better than other popular theories of the attentional blink (e.g., Chun & Potter, 1995; Di Lollo, Kawahara, Shahab Ghorashi, & Enns, 2005; Nieuwenhuis, Gilzenrat, Holmes, & Cohen, 2005; Shapiro, Arnell, & Raymond, 1997) at explaining the pattern of intrusion errors in this task. How might the patterns of errors found in amblyopic vision occur, according to their model? Perhaps there is a delay in the processing of the letters (‘types’) presented to the amblyopic eye, which results in mis-‘tokenization’ such that a previously presented letter becomes erroneously bound to the T1 ‘token’ in the ‘binding pool.’ This might explain the prevalence of pre-T1 errors in amblyopia but not the changes in T2 performance, which result from suppression of the TAE mechanism. One possibility is that the timing of all the letters is slightly erratic in amblyopia.
Bowman and Wyble (2007) explain Lag 1 sparing as the unordered capture of both T1 and T2 in a single sweep of the TAE, and perhaps if their ‘types’ arrive erratically over time this may result in a blurring between Lag 1 and Lag 2 performance in amblyopia. However, the pattern of T2 errors in amblyopia suggests that something else may be going on.

Pelli, Palomares, and Majaj (2004) argued that the phenomenon of crowding involves excessive feature integration between spatially nearby stimuli. They distinguished this spatial crowding from ‘temporal crowding’ in which, they proposed, the illusory conjunction of sometimes spatially distant features arises from a failure of attentive binding. Our results show that in normal vision, color may erroneously bind with letter identity when stimuli are presented in close temporal proximity, as is the case in the attentional blink (Popple & Levi, 2007). However, we did not find evidence for the exchange of features between different letters in the normal fovea, as occurs in spatial crowding in normal peripheral vision and the amblyopic fovea (Levi, Hariharan, & Klein, 2002; Pelli et al., 2004). In the present study, we did find suggestive evidence for this in the form of an increased prevalence of non-stimulus letters in the responses to T2 from amblyopic eyes. This cannot be explained by a bias toward a particular set of letters whenever the target is missed, because that would predict more non-stimulus responses where there were more errors, and instead more non-stimulus responses occurred with the amblyopic eye responding to T2 (although performance was the same as the preferred eye) and not when responding to T1 (although performance was worse with the amblyopic eye). These non-stimulus responses may have been formed by the integration between features of successive letters, resulting in the perception of letters that were not present. Perhaps certain stimulus representations—in the normal periphery and the amblyopic fovea—are simply more vulnerable to crowding and over-integration, whether in space or in time. In space, this vulnerability is inevitable, but in time, it may be contingent on the suppression of the TAE by the tokenization of a prior target. As with the degraded image hypothesis, this idea needs to be tested by investigating the pattern of errors produced by the attentional blink in both the fovea and the periphery, with identical targets, distractors, and time course.

Bonneh et al. (2007) studied temporal crowding in amblyopia by looking at the size threshold for identifying a single RSVP target digit and found that larger sizes were required for target identification in amblyopia (specifically in strabismic amblyopes). We too found a reduction in amblyopic performance on T1 (although not T2). In our study, this effect was due to misreporting preceding targets in place of T1. Bonneh et al. did not report the distribution of errors, as compared with distractor identity. Perhaps the target digit identity was unavailable for binding with the size ‘token’ in Bonneh’s experiment, unless the target was made larger. There is evidence that larger, or more salient, stimuli are processed more rapidly and can be identified with smaller exposure times (Rimmer, Iragui, Klauber, & Katz, 1989). However, the different sizes of the letters used in amblyopic and non-amblyopic eyes in our study probably had little effect on performance, at least by inference from their effects on a normal observer (see Appendix A).

Asper et al. (2003) found only small effects of amblyopia on T2 detection and did not report on T1 performance. However, they may have confounded their results with differences in practice between the amblyopic and preferred eye sessions, since they also showed better performance in the non-dominant eyes of normal observers as compared with their dominant eyes, tested in an earlier session (Asper, 2007; personal communication). We found no such difference in a control test of two experienced observers (Appendix A). We also used a larger sample than they did (12 in place of 10 observers) and a more sensitive task (identifying T2 in place of detecting an ‘X’), thereby improving our chances of detecting a small effect. The small effect we found on the temporal properties of the attentional blink in amblyopic eyes, compared with preferred eyes, suggests that attention itself may be disrupted in amblyopia.

What is attention? Some argue that attention is the preparation for making a saccadic eye movement to an interesting target, in order to better inspect it using high-resolution foveal vision (Findlay & Gilchrist, 2003). If so, it would make sense for the process of attention to be disrupted in amblyopia, because the amblyopic fovea is not necessarily an improvement over peripheral vision in the amblyopic eye, and it would be counterproductive for the individual with amblyopia to make saccadic eye movements to stimuli detected, and perhaps distorted, in this eye. Whatever the circuits in the brain that drive bottom-up pre-attentive vision and the capture of attention by salient stimuli, they may be muted in amblyopia. Evidence for this comes from the tendency in amblyopia to undercount pop-out stimuli (Sharma, Levi, & Klein, 2000) and from the poor localization of such stimuli in amblyopic eyes (Popple & Levi, 2005). Additional evidence comes from the finding that observers with amblyopia show small but significant abnormalities in attentionally tracking multiple suprathreshold objects (Ho et al., 2006; Tiipthya & Levi, 2008). Perhaps the altered time course of attention in amblyopia reflects genuine changes in the process of attention when viewing through amblyopic eyes. Alternatively, the temporal dynamics of masking might be different in amblyopic and preferred eyes. Another possibility is that accurate temporal binding relies on intracortical connectivity, which might be reduced in amblyopia. There is no evidence that selective attention to each eye is possible in the course of normal visual development, but it can be found in certain cases of strabismus, where there is alternating fixation.


The attentional blink is significantly influenced by amblyopia, both in terms of performance and in terms of the pattern of errors made by observers viewing the stimulus with their amblyopic eyes. When viewing with their amblyopic eyes, observers have a shallower attentional blink 200 ms after the first target, compared with the preferred eye, depending on the depth of amblyopia, and they make more error responses consisting of nondistractor letters, when the distractors and targets are confusable. These findings may be the result of an altered time course of attention in amblyopia, perhaps associated with suppression of the amblyopic eye during development and in ongoing binocular single vision.

As a control for normal interocular differences, and for the effects of monocular vs. binocular viewing, author AP (right-eye dominant) completed the experiment monocularly with left and right eyes, as well as binocularly. To control for the effects of changing the letter size for the amblyopic observers, she completed the experiment with 3° as well as 1.5° letters. As a control for impaired acuity in those with severe deficits, she also completed it with 0.3° letters and, to model the effects of amblyopia, with 3° letters 6° in the periphery (below the fovea). Results (shown in Figure A1) suggest that differences between amblyopic eyes were greater than those between the two eyes, or between the 3° and 1.5° letter sizes. The 0.3° condition proved a better model of amblyopic performance than peripheral vision in this example.

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Figure A1. Performance (probability of correct T2 report, given correct report of T1) as a function of Time After T1 for Left and Right eyes, monocular and binocular viewing, and various letter sizes. Error bars indicate standard error for each series.


