Journal of Experimental Psychology:
Human Perception and Performance

0096-1523/16/$12.00 http://dx.doi.org/10.1037/xhp0000267

Perceiving a Continuous Visual World Across Voluntary Eye Blinks

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People blink their eyes every few seconds, but the changes in retinal illumination that accompany eyeblinks are hardly noticed. Furthermore, despite the loss of visual input, visual experience remains continuous across eyeblinks. Two hypotheses were investigated to account for these phenomena. The first proposes that perceptual information is maintained across a blink whereas the second proposes that perceptual information is not maintained but rather postblink perceptual experience is antedated to the beginning of the blink. Two experiments found no evidence for temporal antedating of a stimulus presented during a voluntary eyeblink. In a third experiment subjects judged the temporal duration of a stimulus that was interrupted by a voluntary eyeblink with that of a stimulus presented while the eyes were open. The duration of stimuli that were interrupted by eyeblinks was judged to be 117 ms shorter than that of stimuli presented while the eyes remained open, indicating that blink duration was not accounted for in the perception of stimulus duration. This suggests that perceptual experience is neither maintained nor antedated across eyeblinks, but rather is ignored, perhaps in response to the extraretinal signal that accompanies the eyeblink.

Keywords: eyeblinks, temporal antedating, perceptual memory

Humans typically blink their eyes 12–15 times each minute, sometimes reflexively in response to external stimulation, sometimes voluntarily in response to a command, and most often spontaneously in the absence of any obvious evoking stimulus (Stern, Walrath, & Goldstein, 1984). Although the kinematics of these different kinds of eyeblinks are somewhat different, in all cases vision is almost completely blocked by the closed eyelids for approximately 100–150 ms (Riggs, Volkmann, & Moore, 1981). Despite their frequency, magnitude, and duration, people rarely notice these blank periods, although dimming the lights in a room for the same duration is very noticeable (Volkmann, Riggs, & Moore, 1980). Furthermore, despite the loss of visual input, visual experience remains continuous across eyeblinks. How does this occur?

Volkmann et al. (1980) demonstrated that the blank periods that occur during an eyeblink are not perceived because a central inhibitory signal suppresses vision and thereby minimizes perception of the blackout. In their study a fiber-optic bundle was placed against the roof of the mouth to present light through the back of the eyeball to the retina. Participants wore opaque goggles to ensure that visual stimulation arrived only through the back of the eye. Volkmann et al. found that visual sensitivity for brief decrements in this visual stimulus was reduced by approximately 0.5 log units during a blink and, to a lesser extent, 100 ms before and up to 200 ms after a blink as well, although the light source itself was never physically impeded. This demonstrated that visual suppression during eyeblinks is due, at least in part, to a central inhibitory mechanism. Subsequent experiments showed that visual suppression occurs for reflexive blinks as well as for voluntary blinks (Manning, Riggs, & Komenda, 1983). Possible neural loci for this central inhibition include V1 (Gawne & Martin, 2000) and lateral occipital cortex, particularly area V5/MT (Bristow, Frith, & Rees, 2005), where neural activation is reduced during an eyeblink.

Although visual suppression helps explain why blank periods during blinks are not perceived, it is less clear why visual continuity is perceived across eyeblinks. In the present paper we examined two possible hypotheses for this perceptual experience. The first is that perceptual experience is maintained in memory across the eyeblink. For example, Bristow and colleagues (2005) proposed that a short-term mnemonic signal associated with the blink motor command maintains the preblink percept during the blank period that occurs during an eyeblink. On the basis of an functional magnetic resonance imaging study, they proposed that a region in the medial parieto-occipital cortex (the human equivalent of the macaque V6/V6A complex, area PO) might subserve this purpose because neural activity in the presence (vs. absence) of a blink was greater when a visual stimulus was present compared with when it was absent.

The second hypothesis we examined is based on one that has been proposed to explain the perception of visual continuity across saccadic eye movements. It suggests that perceptual experience is not maintained across a saccade or an eyeblink, but rather that perceptual experience is antedated to the beginning of these eye movement events. Evidence for this kind of temporal antedating has been found for saccadic eye movements via the phenomenon of saccadic chronostasis, which refers to the fact that people consistently overestimate the duration of a stimulus presented during a saccade in comparison with the same stimulus seen at fixation (e.g., Yarrow, Haggard, Heal, Brown, & Rothwell, 2001; Yarrow, Johnson, Haggard, & Rothwell, 2004; Yarrow, Whiteley,

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Haggard, & Rothwell, 2006). In a typical experiment of this kind, subjects saccade to a target that changes during the saccade, then they judge whether the new target stimulus was presented for a longer or shorter time than a subsequently presented reference stimulus. The point of subjective equality (PSE) for the target stimulus is found and compared to the same task performed at fixation. The PSE is consistently shorter in the saccade condition than in the fixation condition, implying that people overestimate the duration of the postsaccadic stimulus. The overestimation is directly related to the duration of the saccade (i.e., it is longer for long saccades than for short saccades), which suggests that the perceived onset of the saccade target is effectively antedated to a moment just before saccade onset. The interpretation of Yarrow and colleagues is that the brain simply assumes that the postsaccadic stimulus was present when the saccade was initiated, yielding a perception of continuity across the saccade. Given that temporal antedating occurs across saccades, it seems possible that it might occur for eyeblinks as well. This would be consistent with the results of Hari, Salmelin, Tissari, Kajola, and Virsu (1994), who found that blinks influenced activation in the posterior parietal cortex shortly after blink offset; they suggested that this activation was essential for stable visual perception across eyeblinks, as though perceptual experience were being antedated to the beginning of the blink (see also Bodis-Wollner, Bucher, & Seelos, 1999).

We investigated the perceptual maintenance and temporal antedating hypotheses in three experiments in which subjects judged the temporal duration of a stimulus that was interrupted by a voluntary eyeblink with that of a stimulus presented while the eyes were open. Of interest was whether blink duration would be taken into account when judging the temporal duration of a stimulus, as predicted by these hypotheses. However, it is important to note that perceptual continuity need not necessarily rely on “filling in” the blank period during an eyeblink. That is, perceived continuity across eyeblinks might occur as a result of the perceptual system simply ignoring the visual interruption caused by the eyeblink. Finding that blink duration is not taken into account when judging the duration of a stimulus would support this hypothesis.

Experiment 1

Experiment 1 used a variant of the procedure that was used by Yarrow and colleagues (2006) in their studies of temporal antedating during saccades to investigate whether temporal antedating also occurs for voluntary eyeblinks.

Method

Participants. Sixteen students from the University of Illinois community participated in Experiment 1. The number of participants was based on Yarrow et al. (2006), who used 18 participants to find significant temporal antedating effects of 30 ms during saccades; the temporal antedating hypothesis predicts effects greater than 100 ms in the case of blinks (because the duration of blinks is much longer than that of saccades), so we assumed that 16 participants would be sufficient to find an effect (this was confirmed by power analyses reported in the *Results*). All participants reported normal or corrected-to-normal vision and were naïve as to the purpose of the experiment. Each received payment for participating in a single 50-min session. The research was conducted in accord with American Psychological Association standards for the ethical treatment of subjects and with the approval of the University of Illinois Institutional Review Board.

Apparatus. The stimuli were presented on a 21-in. cathode ray tube monitor (ViewSonic G810) with a resolution of 800 × 600 pixels and a refresh rate of 85 Hz. Eye movements were recorded with an Eyelink II video-based eyetracker (SR Research Ltd., Mississauga, Ontario, Canada) with temporal resolution of 500 Hz, spatial resolution of 0.1°, and pupil-size resolution of 0.1% of pupil diameter. The output of the eyetracker was analyzed online to detect eyeblinks. Each data sample from the eyetracker contained a timestamp in milliseconds, the velocity and the position of the eye, and the area of the pupil. An eyeblink was defined as a period of missing pupil for at least 6 consecutive milliseconds. Blink onset and blink offset were defined to correspond to the beginning and ending of the period of missing pupil. Custom C code was written to display stimuli and collect responses. The participants’ heads were stabilized with a chin-rest, fixed at 49 cm from the computer monitor. The height of the chair that participants sat in was adjusted for each individual so that their eyes were centered with respect to the display monitor. The display background was light gray (luminance = 86.3 cd/m^2). Participants made manual responses by pressing buttons on a Microsoft Sidewinder digital game controller interfaced with the eyetracking computer.

Procedure. Each participant completed 12 blocks of trials, 6 blocks during which they blinked and 6 blocks during which they did not blink. The blocks alternated between no-blink blocks and blink blocks. Odd-numbered subjects started with a blink block whereas even-numbered subjects started with a no-blink block. An instruction appeared on the display before each block to remind the subject whether it was a blink or no-blink block.

Each block of trials began with a five-position calibration procedure in which the edges and center of the screen were fixated. Participants began each trial by pressing a button on the game controller while fixating a drift correction dot that subtended 0.6° of visual angle (see Figure 1). After the drift correction dot

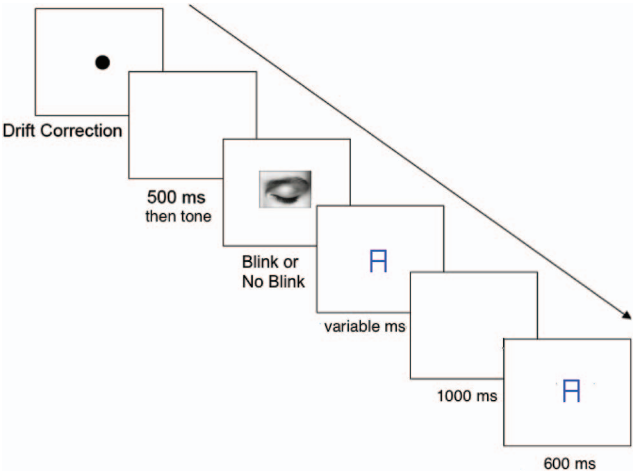

Figure 1. Sequence of events for trials in Experiment 1. See the online article for the color version of this figure.

disappeared, a blank white screen was presented for 600 ms; during the last 130 ms of this presentation a tone also sounded. What happened next depended on the block type. During no-blink blocks a 250-ms delay ensued and then a blue letter resembling a block A (the target stimulus) was presented in the center of the screen for a variable period of time and then erased. The blue letter had chromaticity of $x = .241$, $y = .186$, and luminance = 25.1 cd/m^2, as measured by a Minolta CS-100 Chroma Meter (Minolta Camera Company, Japan). After a 1,000-ms blank screen, a second blue block A (the comparison stimulus) was presented for a constant duration of 600 ms. In contrast, during voluntary blink blocks subjects were instructed to blink shortly after they heard the tone, and when the blink was detected, the blue block A target stimulus was presented while the eyes were closed so that it was visible on the screen when the eyes reopened. The target stimulus was presented as soon as blink onset was detected (i.e., when the computer program detected that the pupil was missing for at least 6 consecutive milliseconds). The target stimulus was presented for a variable period of time and then erased, and then after a 1,000-ms blank screen the blue block A comparison stimulus was presented for a constant duration of 600 ms. In both conditions subjects were instructed to report whether the letter they saw first or the letter they saw second was seen for a longer period of time, and they indicated their response by pressing the left (if the first letter seemed to have a longer duration) or right (if the second letter seemed to have a longer duration) trigger on the game controller. No feedback was given. The duration of the target stimulus was then adjusted on the next trial based on this response, as determined by the modified binary search (MOBS) procedure (low boundary 200 ms, high boundary 1,600 ms, initial presentation time 900 ms, five reversals to terminate), eventually reaching a value that was subjectively equal to the fixed duration (600 ms) of the comparison stimulus (Tyrrell & Owens, 1988). The MOBS procedure yields efficient threshold estimates by combining binary search and bracketing techniques; Monte Carlo simulations show that it provides more precise measures with fewer stimulus presentations than conventional staircase techniques (see Tyrrell & Owens, 1988, for further details). Blocks finished when the MOBS criteria were satisfied, which typically took 6–25 trials. Six estimates of the subjective duration of the target stimulus were collected per condition (blink vs. no-blink) for each subject, one per block.

Results

Mean blink latency (i.e., when the eyelids started to move) from tone offset was 403 ms ($SD = 248$ ms). Mean blink duration (i.e., total eyelid movement time) was 251 ms ($SD = 121$ ms). On average, the pupil was covered beginning 432 ms ($SD = 249$ ms) after tone offset and it remained covered for an average of 130 ms ($SD = 73$ ms).

Recall that the target stimulus was presented as soon as the pupil was covered but it did not become visible to the subject until after the pupil became uncovered an average of 130 ms later. To determine whether perception of the target stimulus was temporally antedated to the beginning of the blink, for each subject a mean subjective duration estimate (PSE) for the target stimulus was calculated by taking the average of the MOBS termination values for the six blocks in each condition. In the blink condition this value was corrected post hoc to correct for the amount of time that the stimulus had been presented while the eyes were closed (i.e., pupil was covered), similar to the experiments of Yarrow and colleagues. The temporal antedating hypothesis predicts that the subjective duration estimate (PSE) of the target stimulus should be shorter under blink than under no-blink conditions because under blink conditions participants antedate their perception of the target stimulus (which is visible only after the blink has ended) to the beginning of the blink. If antedating is done to the time of blink initiation, then the PSE for voluntary blinks should be 251 ms shorter than its corresponding no-blink control (because this was the duration of the voluntary blink), whereas it should be 130 ms shorter if it is merely antedated to the time that the pupil is first covered by the eyelids. A post hoc power analysis using the G*Power analysis program (Faul, Erdfelder, Lang, & Buchner, 2007) indicated that we had power of 0.99 to detect an effect of 130 ms.

Contrary to the predictions of the temporal antedating hypothesis, the PSE for voluntary blink trials ($M = 676$ ms, $SE = 39$ ms) was longer (not shorter) than the PSE for no-blink trials ($M = 650$ ms, $SE = 20$ ms), but the difference was not significant, $t(15) = 0.89$, $SD = 120$, $p > .38$. The effect size (d) was 0.19, based on the procedure described by Dunlap, Cortina, Vaslow, and Burke (1996) for paired-sample t tests. The scaled ($r = 1$) JZS Bayes factor in support of the null hypothesis was 3.65 (Rouder, Speckman, Sun, Morey, & Iverson, 2009).

Discussion

If people antedate their perception of a stimulus that is presented during a blink to the beginning of the blink, then the duration of such a stimulus should be overestimated by 130–250 ms relative to the duration of a stimulus that is presented while the eyes remain open. We found instead only a small and nonsignificant difference (in the wrong direction) in the perceived duration of a stimulus presented during a blink compared with a no-blink control. These results are inconsistent with the hypothesis that temporal antedating may occur for stimuli presented during eyeblinks, although such antedating has been found for saccadic eye movements.

One perhaps nonoptimal aspect of the procedure that we used in Experiment 1 was that the target stimulus was presented as soon as pupil occlusion was detected; as a consequence, the stimulus was unseen for the period of time that the pupil was covered and this time then had to be subtracted from the perceived duration estimate calculated by the MOBS algorithm. It seemed possible that this might yield an inaccurate estimate of the apparent duration of the target stimulus; therefore, in Experiment 2 we replicated the procedure of Experiment 1 with the exception that the target stimulus was presented as soon as the pupil became uncovered during the eyeblink (i.e., at the end of the pupil occlusion period rather than at the beginning). Of interest was whether the duration of the stimulus would be antedated to the beginning of the blink, as predicted by the temporal antedating hypothesis.

Experiment 2

Method

Participants. Sixteen students from the University of Illinois community participated in Experiment 2. All participants reported normal or corrected-to-normal vision and were naïve as to the purpose of the experiment. Each received payment for participating in a single 50-min session. None had participated in the first experiment.

Apparatus and procedure. The apparatus and the procedure were the same as in Experiment 1, except that the target stimulus was presented when the pupil became uncovered at the end of the blink (more specifically, given our refresh rate of 85 Hz, within 12 ms from detection of blink offset) instead of at the beginning of pupil occlusion. Because of visual blink suppression, perceptually it appeared as though the stimulus had been presented while the eyes were still closed.

Results

Mean blink latency from tone offset was 522 ms ($SD = 462$ ms). Mean blink duration was 255 ms ($SD = 146$ ms). On average the pupil was covered beginning 537 ms ($SD = 435$ ms) after tone offset and it remained covered for an average of 172 ms ($SD = 140$ ms).

To determine whether perception of the target stimulus was temporally antedated to the beginning of the blink, for each subject a mean subjective duration estimate (PSE) for the target stimulus was calculated by taking the average of the MOBS termination values for the six blocks in each condition. Recall that the temporal antedating hypothesis predicts that the subjective duration estimate (PSE) of the target stimulus should be shorter under blink than under no-blink conditions because under blink conditions participants antedate their perception of the target stimulus to the beginning of the blink. If antedating is done to the time of blink initiation (i.e., when the eyelids start to move), then the PSE for blinks should be 255 ms shorter than in the no-blink control condition (because this was the duration of the blink), whereas it should be 172 ms shorter if it is merely antedated to the time that the pupil is first covered by the eyelids (our power to detect a 172-ms effect was >0.99). In fact, the PSE for blink trials ($M = 651$ ms, $SE = 49$ ms) was longer than the PSE for no-blink trials ($M = 602$ ms, $SE = 44$ ms) but the difference was not significant, $t(15) = 1.31$, $SD = 149$, $p > .21$, $d = 0.26$. The scaled ($r = 1$) JZS Bayes factor in support of the null hypothesis was 2.43.

Omnibus analysis. Because Experiment 2 was a replication of Experiment 1 (except for a minor change in procedure), we conducted an omnibus analysis combining the data from the two experiments. The PSE for blink trials ($M = 664$ ms, $SE = 31$ ms) was longer than the PSE for no-blink trials ($M = 626$ ms, $SE = 24$ ms), but the difference was not significant, $t(31) = 1.6$, $SD = 134$, $p = .12$, $d = 0.24$. The scaled ($r = 1$) JZS Bayes factor in support of the null hypothesis was 2.20. Note that the difference was also in the direction opposite to that predicted by the temporal antedating hypothesis.

Discussion

The results of Experiment 2 replicated those of Experiment 1. The temporal antedating hypothesis predicts that the duration of a stimulus presented during a voluntary eyeblink should be overestimated by 172–250 ms relative to the duration of a stimulus that is presented while the eyes remain open. We found instead only a small and nonsignificant difference in the perceived duration of a stimulus presented during a blink compared with a no-blink control. These results are inconsistent with the hypothesis that the perception of a stimulus presented during an eyeblink is antedated to the beginning of the eyeblink, although such antedating has been found for saccadic eye movements.

One weakness of the first two experiments is that the conclusion that temporal antedating does not occur for eyeblinks relies on accepting the null hypothesis. Therefore, in Experiment 3 we examined the temporal antedating hypothesis in a new way by having subjects blink while a stimulus was already present on the display (as opposed to presenting the stimulus during the blink) and examining whether blink duration was taken into account when evaluating the duration of the stimulus. This would be expected under the temporal antedating hypothesis, and it is also predicted by the alternative hypothesis that perceptual information is maintained across an eyeblink to produce uninterrupted visual experience (e.g., Bristow et al., 2005).

Experiment 3

In Experiment 3 the MOBS procedure was used to calculate the PSE in stimulus duration between a constant-duration stimulus, the viewing of which was interrupted by an eyeblink (in the blink condition) or not interrupted by an eyeblink (in the no-blink condition) and a comparison stimulus that varied in duration. A letter resembling a blue block A was presented for 1,000 ms and participants either blinked or did not blink during its presentation. They then compared their perception of how long the letter had been presented with a comparison stimulus that varied in duration. Both the temporal antedating and perceptual maintenance hypotheses predict that the PSEs should be equal under blink and no-blink conditions, either because subjects antedate their perceptual experience of the stimulus to the beginning of the blink (in the case of the temporal antedating hypothesis) or because stimulus information is maintained in memory during the blink (in the case of the perceptual maintenance hypothesis).

Method

Participants. Sixteen students from the University of Illinois community participated in Experiment 3. All participants reported normal or corrected to normal vision and were naïve as to the purpose of the experiment. Each received payment for participating in a single 50-min session. None had participated in either of the first two experiments.

Apparatus and procedure. The apparatus was the same as in Experiments 1 and 2. Each participant completed six blocks during which they blinked and six blocks during which they did not blink. Order (blink condition first or no-blink condition first) was counterbalanced across subjects. An instruction appeared on the display before each block to remind the subject whether it was a blink or no-blink block.

Each block of trials began with a five-position calibration procedure in which the edges and center of the screen were fixated. Participants began each trial by pressing a button on the game controller while fixating a drift correction dot that subtended 0.6° of visual angle (see Figure 2). After the drift correction dot disappeared, a blank white screen was presented for 529 ms. Then, in blink and no-blink conditions, a blue letter resembling a block

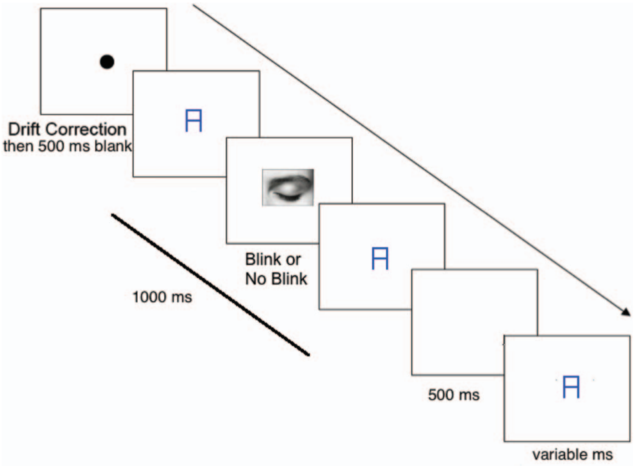

Figure 2. Sequence of events for trials in Experiment 3. See the online article for the color version of this figure.

A (the target stimulus) was presented in the center of the screen for 1,000 ms. During no-blink blocks subjects were instructed to keep their eyes open. On voluntary blink blocks subjects were instructed to blink as soon as the initial letter was presented. After the 1,000-ms presentation of the target stimulus, in both conditions a 529-ms blank screen was then presented, followed by the presentation of a second blue block A (the comparison stimulus), the duration of which was determined by the MOBS procedure (low boundary 400 ms, high boundary 1,600 ms, initial presentation time chosen randomly between 600 and 1,400 ms, five reversals to terminate), eventually reaching a value that was subjectively equal to the fixed duration (1,000 ms) of the target stimulus. Six estimates of the subjective duration of the target stimulus were collected per condition (blink vs. no-blink) for each subject, one per block.

In both conditions subjects were instructed to report whether the letter they saw first or the letter they saw second was seen for a longer period of time, and they indicated their response by pressing the left (if the first letter seemed to have a longer duration) or right (if the second letter seemed to have a longer duration) trigger on the game controller. No feedback was given.

Results

Mean blink latency from target stimulus onset was 433 ms (SD = 228 ms). Mean blink duration was 219 ms (SD = 50 ms). On average, the pupil was covered beginning 469 ms (SD = 227 ms) after target onset and it remained covered for an average of 114 ms (SD = 50 ms). Thus, the target stimulus was visible for an average of 417 ms after blink offset (as measured from the end of pupil occlusion).

As in the first two experiments, for each subject a mean subjective duration estimate (PSE) for the target stimulus was calculated by taking the average of the MOBS termination values for the six blocks in each condition (blink vs. no-blink). The temporal antedating hypothesis and the perceptual maintenance hypothesis predict that the subjective duration estimate (PSE) of the target stimulus should be equal under blink and no-blink conditions because under blink conditions participants take the duration of the blink into account, either by antedating their perception of the target stimulus to the beginning of the blink or by maintaining a memory representation of the stimulus during the blink. Instead, we found that the PSE for blink trials (M = 851 ms, SE = 34 ms) was significantly shorter than the PSE for no-blink trials (M = 968 ms, SE = 35 ms), $t(15) = 3.52$, SD = 132, $p < .005$, d = 0.88, power > .90). The scaled (r = 1) JZS Bayes factor in support of the alternative hypothesis (i.e., blink mean is different from no-blink mean) was 14.2. Note that the PSE under blink conditions was 117 ms shorter than under no-blink conditions, which is almost identical to the duration that the pupil was covered during voluntary blinks (114 ms). This provides strong support for the hypothesis that the time that the stimulus was occluded by the closed eyelids was ignored in subjects' estimation of how long the stimulus was presented.

Discussion

In this experiment the MOBS procedure was used to calculate the PSE in stimulus duration between a constant-duration stimulus, the viewing of which was interrupted by an eyeblink or not, and a comparison stimulus that varied in duration. The temporal antedating hypothesis predicts that the PSEs should be equal under blink and no-blink conditions because subjects antedate their perceptual experience of the stimulus to the beginning of the blink, thereby filling in the interval during the blink. The perceptual maintenance hypothesis makes the same prediction because it holds that stimulus information is maintained in memory during the blink. The results of Experiment 3 were inconsistent with both hypotheses; instead, it appears that participants did not take blink duration into account when assessing the duration of the stimulus. Participants judged a stimulus that was interrupted by a blink as being 117 ms shorter than it actually was relative to a no-blink condition. The duration of the target stimulus under no-blink conditions was also underestimated to some extent because of the well-known time-order error in stimulus comparison (e.g., Needham, 1934; Woodrow, 1935), which is probably due to a fading mental representation of the first stimulus during the interstimulus interval before its comparison with the comparison stimulus (e.g., Schab & Crowder, 1988).

Although subjects underestimated the duration of the stimulus interrupted by an eyeblink, it appears that they did perceive the stimulus as being continuous. This is shown by the finding that the perceived duration of the stimulus was considerably longer than its postblink presentation time. The mean postblink duration of the stimulus interrupted by a voluntary blink was 417 ms, but the perceived duration of this stimulus was 851 ms. Thus, it appears that stimulus continuity was perceived although the duration of the blink itself was ignored in subjects' estimation of its duration.

General Discussion

We investigated two hypotheses that have been proposed to explain why vision appears continuous across the temporal interruptions caused by eyeblinks. The first, the temporal antedating hypothesis, claims that people antedate their perception of a stimulus presented during a blink to the time of blink onset, producing the perception of a continuously present stimulus. Two experiments used a variant of procedure used by Yarrow and colleagues (e.g., Yarrow et al., 2001, 2004, 2006) to study temporal antedating across saccades to investigate whether temporal antedating also occurs across eyeblinks. Participants judged the duration of a stimulus that was presented at the beginning (Experiment 1) or end (Experiment 2) of an eyeblink against that of a constant duration stimulus presented during fixation. If people antedate their perception of a stimulus that is presented during a blink to the beginning of the blink, then the duration of such a stimulus should be overestimated by approximately 130–250 ms (i.e., the duration of the blink) relative to the duration of a stimulus that is presented while the eyes remain open. We found instead only small and nonsignificant differences in the perceived duration of a stimulus presented during a voluntary eyeblink compared with a no-blink control. These results are inconsistent with the hypothesis that temporal antedating occurs for stimuli presented during eyeblinks, although Yarrow and colleagues found that such antedating occurs for saccadic eye movements.

A third experiment examined the temporal antedating hypothesis in a different way, by having subjects blink while a stimulus was already present on the display (as opposed to presenting the stimulus during the blink) and examining whether blink duration was taken into account when evaluating the duration of the stimulus. This would be expected under the temporal antedating hypothesis, and it is also predicted by the second hypothesis that we considered, the perceptual maintenance hypothesis, which posits that perceptual information is maintained across an eyeblink to produce uninterrupted visual experience (e.g., Bristow et al., 2005). This experiment calculated the PSE in stimulus duration between a constant-duration stimulus, the viewing of which was interrupted by an eyeblink or not, and a comparison stimulus that varied in duration. The results of this experiment were inconsistent with the temporal antedating and perceptual maintenance hypotheses; rather, participants judged a stimulus that was interrupted by a blink as being 117 ms shorter than it actually was relative to a no-blink condition. The average blink duration was 114 ms; thus, instead of stimulus information being antedated or maintained in memory across an eyeblink, it appears that it is simply ignored instead. Despite this, it appears that stimulus continuity was preserved because participants perceived the duration of the blink-interrupted stimulus as being considerably longer than its postblink presentation time. Similar results using a somewhat different procedure were reported in abstract form by Duyck, Collins, and Wexler (2015).

In all of our experiments we assessed the subjective duration of visual experience across an eyeblink against a no-blink control in which the visual stimulus was uninterrupted. Because visual experience across an eyeblink appears to be continuous, it seemed to us that using a continuous visual stimulus was the appropriate control condition to use. However, one could conceivably explore other conditions, such as mimicking the retinal effects of an eyeblink by blanking the display for durations equivalent to those of eyeblinks. Although this may mimic the retinal effect of an eyeblink in some ways, perceptually such interruptions are very salient and lead to a stimulus appearing to be discontinuous rather than continuous. As noted earlier, Volkmann and colleagues (1980) showed that people rarely notice the blank periods produced by an eyeblink, but dimming the lights in a room for the same duration is very noticeable. Because we were interested in investigating why the visual world appears continuous (as opposed to discontinuous) across eyeblinks, a continuous visual control condition rather than a discontinuous one seemed appropriate to us. Furthermore, others have shown that visual stimuli that are discontinuous in time are actually perceived to be longer than visual stimuli that are continuous, which is the opposite of what we found (e.g., Kanai, Paffen, Hogendoorn, & Verstraten, 2006; Yuasa & Yotsumoto, 2015). Thus, we are confident that our results are due to stimulus duration being ignored during eyeblinks as opposed to being caused by retinal differences between the blink and no-blink control conditions.

Having ruled out the temporal antedating and perceptual maintenance hypotheses, the question still remains: Why does the visual world appear continuous across eyeblinks? It is important to note that although the temporal antedating and perceptual maintenance hypotheses attempt to explain perceptual continuity via mechanisms that “fill in” the blank period during the blink (so that the perceived duration of a stimulus interrupted by an eyeblink reflects its actual physical duration), perceived continuity might instead result from the perceptual system simply ignoring the visual interruption caused by the eyeblink. For example, the motor signal (efferent signal) that accompanies an eyeblink may signal to the perceptual system that any disruption in phenomenal experience that accompanies an eyeblink is to be ignored because it is caused by the blink and not by a change in the external world (Deubel, Bridgeman, & Schneider, 2004). In support of this hypothesis, Deubel and colleagues (2004) found that a blink operated differently than a blank interval when it comes to the detection of stimulus displacements across saccades. Detecting that a stimulus has been displaced is difficult if the displacement occurs during a saccade (such that the displaced stimulus is visible immediately after the saccade ends), but Deubel, Bridgeman, and Schneider (1998); Deubel and Schneider (1994); and Deubel, Schneider, and Bridgeman (1996) found that displacement detection improved dramatically if a blank interval separated saccade offset and the presentation of the displaced stimulus. Deubel and colleagues (2004) found that replacing the blank interval with an eyeblink of similar duration had no beneficial effect, however subjects were no better at detecting stimulus displacements when vision was interrupted by a blink than they were when no blank interval separated saccade offset and stimulus onset. Deubel et al. (2004) proposed that the extraretinal signal that accompanies an eyeblink allows the perceptual system to distinguish between internally generated and externally generated sources of temporary object disappearances so that blinks are interpreted differently than blanks. In other words, Deubel et al. (2004) found that blink duration was ignored by the perceptual system, just as we found in our third experiment.

In conclusion, visual experience remains continuous across eyeblinks despite the loss of visual input that they produce. Our results show that perceptual experience is neither maintained nor antedated across eyeblinks, but rather is ignored, presumably in response to the extraretinal signal that accompanies the eyeblink.

References

Bodis-Wollner, I., Bucher, S. F., & Seelos, K. C. (1999). Cortical activation patterns during voluntary blinks and voluntary saccades. *Neurology, 53,* 1800–1805. http://dx.doi.org/10.1212/WNL.53.8.1800

Bristow, D., Frith, C., & Rees, G. (2005). Two distinct neural effects of blinking on human visual processing. *NeuroImage, 27,* 136–145. http://dx.doi.org/10.1016/j.neuroimage.2005.03.037

Deubel, H., Bridgeman, B., & Schneider, W. X. (1998). Immediate postsaccadic information mediates space constancy. *Vision Research, 38,* 3147–3159. http://dx.doi.org/10.1016/S0042-6989(98)00048-0

Deubel, H., Bridgeman, B., & Schneider, W. X. (2004). Different effects of eyelid blinks and target blanking on saccadic suppression of displacement. *Perception & Psychophysics, 66,* 772–778. http://dx.doi.org/10.3758/BF03194971

Deubel, H., & Schneider, W. X. (1994). Perceptual stability and postsaccadic visual information: Can man bridge a gap? *Behavioral and Brain Sciences, 17,* 259–260. http://dx.doi.org/10.1017/S0140525X00034397

Deubel, H., Schneider, W. X., & Bridgeman, B. (1996). Postsaccadic target blanking prevents saccadic suppression of image displacement. *Vision Research, 36,* 985–996. http://dx.doi.org/10.1016/0042-6989(95)00203-0

Dunlap, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. J. (1996). Meta-analysis of experiments with matched groups or repeated measures designs. *Psychological Methods, 1,* 170–177. http://dx.doi.org/10.1037/1082-989X.1.2.170

Duyck, M., Collins, T., & Wexler, M. (2015). Does time stop when we blink? *Journal of Vision, 15,* 370. http://dx.doi.org/10.1167/15.12.370

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39,* 175–191. http://dx.doi.org/10.3758/BF03193146

Gawne, T. J., & Martin, J. M. (2000). Activity of primate V1 cortical neurons during blinks. *Journal of Neurophysiology, 84,* 2691–2694.

Hari, R., Salmelin, R., Tissari, S. O., Kajola, M., & Virsu, V. (1994). Visual stability during eyeblinks. *Nature, 367,* 121–122. http://dx.doi.org/10.1038/367121b0

Kanai, R., Paffen, C. L., Hogendoorn, H., & Verstraten, F. A. (2006). Time dilation in dynamic visual display. *Journal of Vision, 6,* 8. http://dx.doi.org/10.1167/6.12.8

Manning, K. A., Riggs, L. A., & Komenda, J. K. (1983). Reflex eyeblinks and visual suppression. *Perception & Psychophysics, 34,* 250–256. http://dx.doi.org/10.3758/BF03202953

Needham, J. G. (1934). The time-error in comparison judgments. *Psychological Bulletin, 31,* 229–243. http://dx.doi.org/10.1037/h0070945

Riggs, L. A., Volkmann, F. C., & Moore, R. K. (1981). Suppression of the blackout due to blinks. *Vision Research, 21,* 1075–1079. http://dx.doi.org/10.1016/0042-6989(81)90012-2

Rouder, J. N., Speckman, P. L., Sun, D., Morey, R. D., & Iverson, G. (2009). Bayesian t tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin & Review, 16,* 225–237. http://dx.doi.org/10.3758/PBR.16.2.225

Schab, F. R., & Crowder, R. G. (1988). The role of succession in temporal cognition: Is the time-order error a recency effect of memory? *Perception & Psychophysics, 44,* 233–242. http://dx.doi.org/10.3758/BF03206292

Stern, J. A., Walrath, L. C., & Goldstein, R. (1984). The endogenous eyeblink. *Psychophysiology, 21,* 22–33. http://dx.doi.org/10.1111/j.1469-8986.1984.tb02312.x

Tyrrell, R. A., & Owens, D. A. (1988). A rapid technique to assess the resting states of the eyes and other threshold phenomena: The Modified Binary Search (MOBS). *Behavior Research Methods, Instruments & Computers, 20,* 137–141. http://dx.doi.org/10.3758/BF03203817

Volkmann, F. C., Riggs, L. A., & Moore, R. K. (1980). Eyeblinks and visual suppression. *Science, 207,* 900–902. http://dx.doi.org/10.1126/science.7355270

Woodrow, H. (1935). The effect of practice on time-order errors in the comparison of temporal intervals. *Psychological Review, 42,* 127–152. http://dx.doi.org/10.1037/h0063696

Yarrow, K., Haggard, P., Heal, R., Brown, P., & Rothwell, J. C. E. (2001). Illusory perceptions of space and time preserve cross-saccadic perceptual continuity. *Nature, 414,* 302–305. http://dx.doi.org/10.1038/35104551

Yarrow, K., Johnson, H., Haggard, P., & Rothwell, J. C. (2004). Consistent chronostasis effects across saccade categories imply a subcortical efferent trigger. *Journal of Cognitive Neuroscience, 16,* 839–847. http://dx.doi.org/10.1162/089892904970780

Yarrow, K., Whiteley, L., Haggard, P., & Rothwell, J. C. (2006). Biases in the perceived timing of perisaccadic perceptual and motor events. *Perception & Psychophysics, 68,* 1217–1226. http://dx.doi.org/10.3758/BF03193722

Yuasa, K., & Yotsumoto, Y. (2015). Opposite distortions in interval timing perception for visual and auditory stimuli with temporal modulations. *PLoS One, 20,* e0135646. http://dx.doi.org/10.1371/journal.pone.0135646

Received October 18, 2015
Revision received May 10, 2016
Accepted May 10, 2016 ■