Memory, 2014
Vol. 22, No. 8, 898–906, http://dx.doi.org/10.1080/09658211.2013.847959

Short-term memory across eye blinks

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(*Received 18 April 2013; accepted 19 September 2013*)

The effect of eye blinks on short-term memory was examined in two experiments. On each trial, participants viewed an initial display of coloured, oriented lines, then after a retention interval they viewed a test display that was either identical or different by one feature. Participants kept their eyes open throughout the retention interval on some blocks of trials, whereas on others they made a single eye blink. Accuracy was measured as a function of the number of items in the display to determine the capacity of short-term memory on blink and no-blink trials. In separate blocks of trials participants were instructed to remember colour only, orientation only, or both colour and orientation. Eye blinks reduced short-term memory capacity by approximately 0.6–0.8 items for both feature and conjunction stimuli. A third, control, experiment showed that a button press during the retention interval had no effect on short-term memory capacity, indicating that the effect of an eye blink was not due to general motoric dual-task interference. Eye blinks might instead reduce short-term memory capacity by interfering with attention-based rehearsal processes.

Keywords*:* Short-term memory; Capacity; Eye blinks; Change detection; Attention.

People blink their eyes about every 4 seconds (Ponder & Kennedy, 1927). Some eye blinks are reflexive, made in response to environmental stimulation, while others are endogenous, influenced by one's thoughts and emotions (Stern, Walrath, & Goldstein, 1984). Eye blinks can also be made voluntarily, of course, in response to some instruction. During an eye blink vision is almost completely blocked by the closed eyelids for approximately 100–150 ms (Riggs, Volkmann, & Moore, 1981). The visual interruptions caused by eye blinks are rarely noticed, however, because vision is suppressed during a blink (and to a lesser extent before and after it as well), so that the visual interruption is not perceived (Volkmann, Riggs, & Moore, 1980).

Despite their ubiquity, the possible effect of eye blinks on cognition has received very little study (for a review see Irwin & Thomas, 2010). The purpose of the present research was to investigate short-term memory across eye blinks. Of particular interest is whether eye blinks reduce the capacity of short-term memory. Casual observation suggests that they might—for example, if one happens to blink while one's computer display is updated during a screen refresh, it is not always immediately apparent that the post-blink visual display is different from the pre-blink display.

Why might eye blinks interfere with short-term memory capacity? There is substantial evidence that rehearsal in visual short-term memory relies on visual selective attention (for a review see Awh & Jonides, 2001). Attention appears to protect representations in visual short-term memory while they are being retained (Matsukura, Luck, & Vecera, 2007; see also Kuo, Stokes, & Nobre, 2012). Previous research has shown that saccadic eye movements (which involve both overt and covert shifts of attention) interfere with short-term memory for spatial locations (e.g., Lawrence,

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Myerson, & Abrams, 2004; Pearson & Sahraie, 2003), perhaps by interfering with rehearsal mechanisms. Recent evidence has shown that eye blinks also influence attentional allocation (Irwin, 2011); in particular, attention moves downward before an eye blink in an involuntary fashion. It seems possible that this involuntary shift of attention might also interfere with the maintenance of information in short-term memory, leading to a decrement in performance.

The scant experimental evidence that exists about the possible effects of eye blinks on short-term memory is somewhat contradictory. An experiment conducted by O'Regan, Deubel, Clark, and Rensink (2000) suggests that short-term memory across eye blinks is quite poor. In this study a change-detection procedure was used in which a picture presented on a computer screen changed in some fashion (e.g., an object changed colour, changed position, or appeared or disappeared) during an eye blink. Participants were instructed to look for changes, but they were not told that the changes occurred during eye blinks. O'Regan et al. (2000) found that changes during eye blinks were frequently undetected; for example, even when participants were directly fixating the change location, they failed to detect the change more than 40% of the time. Higgins, Irwin, Wang, and Thomas (2009) also found that eye blinks interfered with short-term memory for object position. In the relevant condition of their study a target dot was presented for 100 ms, then was re-presented after a 750-ms delay in a new position (either above, below, right, or left of the initial position). Participants were significantly more accurate at reporting the direction of target displacement when they kept their eyes open than when they blinked during the retention interval, indicating that eye blinks interfere with short-term memory for object position. In contrast to O'Regan et al. (2000) and Higgins et al. (2009), Thomas and Irwin (2006) found that eye blinks did not interfere with short-term memory. Participants in their experiment performed a Sperling (1960) partial-report task under blink and no-blink conditions. Thomas and Irwin found that eye blinks interfered with performance only at short cue delays, suggesting that eye blinks interfere with iconic memory but not with short-term memory.

In sum, it is not clear from previous research to what extent eye blinks affect short-term memory. In addition the few previous studies that have examined this question were not well suited for quantifying the possible effect of eye blinks on short-term memory capacity. The present study used a well-understood method of investigating short-term memory, the Luck and Vogel (1997) version of the change detection paradigm (Pashler, 1988; Phillips, 1974), to measure the capacity of short-term memory for simple feature and conjunction stimuli under conditions in which participants either blinked or did not blink their eyes during the retention interval.

EXPERIMENT 1

On each trial participants viewed an initial display of coloured, oriented lines, then after a retention interval they viewed a test display that was either identical or different by one feature. Participants kept their eyes open throughout the retention interval on some blocks of trials, whereas on others they blinked once during the retention interval. Accuracy was measured as a function of the number of items in the display to determine the capacity of short-term memory on blink and no-blink trials. In separate blocks of trials participants were instructed to remember colour only, orientation only, or both colour and orientation.

Method

Participants. A total of 12 students from the University of Illinois community were recruited for this experiment. Participants reported normal or corrected to normal vision and were naïve as to the purpose of the experiment. They received payment for participating in a single 90-minute session.

Apparatus. Stimuli were presented on a 21-inch monitor with resolution of 800 × 600 pixels and a refresh rate of 85 Hz. Eye movements and blinks 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 analysed offline to detect eye movements and eye blinks. An eye movement was classified as a saccade when its distance exceeded 0.2° and its velocity reached 30°/s, or when its distance exceeded 0.2° and its acceleration reached $9500°/s^2$. Movements of the eyelids that occluded the pupil for at least 6 sequential ms were classified as eye blinks. Custom C code was written to display stimuli and collect responses. Participants' heads were stabilised with a chin-rest, fixed at 57 cm from the computer monitor. The height of the chair that participants sat in was adjusted for each individual so that their eyes were centred with respect to the display monitor. The display background was light grey (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. On each trial participants viewed an initial display followed by a test display, and they had to indicate whether the two displays were identical or different. The stimuli were oriented bars of different colours. Four orientations were used: 0, 90, 45, and 315 degrees tilted from vertical. Four colours were used: blue (RGB value: 0, 0, 255), green (RGB value: 0, 255, 0), red (RGB value: 255, 0, 0), and black (RGB value: 0, 0, 0). Each initial display contained two, four, or eight items, comprising randomly chosen combinations of colours and orientations. The items were randomly positioned within a virtual 7 × 7 grid that subtended 9.3° by 11.4°. Each bar subtended 0.1° by 1.2°. The test display was either identical to the initial display, or differed by only one feature (i.e., either the colour or the orientation of one item was different).

Each participant completed three tasks. In one task only their memory for colour was tested (i.e., on *different* trials only the colour of one item was changed). A second task tested only their memory for orientation. A third task required participants to remember both colour and orientation, because in the test display either one colour or one orientation was different from the initial display. This third ("conjunction") condition provides a measure of dual-feature memory (e.g., Wheeler & Treisman, 2002). Participants completed blink and no-blink versions of each task, producing six experimental conditions in total. Each condition was presented in a separate block, with 90 trials in each block. Each block contained 30 trials at each display size (2, 4, or 8), with half of these trials containing a test display that was identical to the initial display, and half containing a test display that was different from the initial display in one feature. The order of the blocks was counterbalanced across participants, with the restriction that blink and no-blink versions of each task immediately followed one another. Participants were informed before each block which task they were to perform (and hence what kind of change to look for) and whether they should blink or keep their eyes open on each trial.

Each block of trials began with a five-position calibration procedure in which the edges and centre of the screen were fixated; a drift correction procedure was completed at the beginning of each experimental trial. The circular calibration/drift correction dot subtended 0.6°.

Participants began each trial by pressing a button on the game controller while fixating the drift correction dot. After the drift correction dot disappeared, a blank white screen was presented for 506 ms. The initial display was then presented for 506 ms. The display was then blank for a 900-ms retention interval, and then the test display was presented for a maximum of 2000 ms (but participants usually responded before this time elapsed). Participants kept their eyes open throughout the initial display and retention interval on no-blink trials, whereas on blink trials they were instructed to make a single eye blink during the retention interval. On each trial the participant indicated (by pressing one of two buttons on the game controller) whether the test display was identical or different from the initial display.

Results and discussion

No-blink trials in which a participant blinked before the onset of the test display (23.2% of no-blink trials) were excluded from analysis. Blink trials in which a participant did not blink before the onset of the test display (12.5% of blink trials) were also excluded from analysis. Mean blink latency (measured from the onset of the initial display) was 623 ms (SD = 81 ms) and mean blink duration was 489 ms (SD = 253 ms). Thus, on average, the eye blink started 117 ms after the offset of the initial display and ended 294 ms before the onset of the test display. Very few saccades were made during the presentation of the initial display or the test display so it was not possible to examine their effects on performance. Mean reaction time to respond same or different to the test display was 812 ms on no-blink trials and 853 ms on blink trials.

Percent correct on same and different trials was converted into estimates of the number of items held in memory using the K formula proposed by Pashler (1988): $K = N((\text{hit rate} - \text{false alarm rate})/(1 - \text{false alarm rate}))$, where K = capacity and N = display size (2, 4, or 8). As Rouder, Morey, Morey, and Cowan (2011) have noted, this is the appropriate measure of capacity to use when a whole-display change detection procedure is employed. Capacity as a function of display size for the three different tasks under blink and no-blink conditions is shown in Figure 1.

The capacity estimates (K) were analysed in a three-way ANOVA with task, blink condition, and display size as repeated-measures factors. The results are summarised in Table 1. Scheffé simultaneous confidence intervals were constructed based on the error term for each effect to examine comparisons of interest.

The main effect of task was significant: Short-term memory capacity was higher in the colour memory task (K = 3.29) than in the orientation (K = 2.51) and conjunction (K = 2.54) memory tasks (95% confidence interval for the difference between two means = ±0.44). The main effect of display size was also significant: Capacity increased as display size increased from 2 (K = 1.85) to 4 (K = 3.13) items, but there was no difference between set sizes of 4 and 8 (K = 3.36) items, 95% confidence interval for the difference between two means = ± 0.61. The interaction between task and display size was significant: The effect of display size was larger in the colour (2.46 item increase) memory task than in the orientation (0.91 item increase) and conjunction (1.14. item increase) memory tasks (95% confidence interval for the interaction = ±0.88).

TABLE 1
Summary of ANOVA, Experiment 1

Effect	*df*	*F*	*p*	*MSe*
T	2, 22	13.88	< .001	1.009
B	1, 11	1.55	> .20	1.399
S	2, 22	24.31	< .001	1.943
T × B	2, 22	0.13	> .85	1.070
T × S	4, 44	4.73	< .005	0.903
B × S	2, 22	3.47	< .05	0.806
T × B × S	4, 44	0.13	> .95	1.221

Factors are Task (T), Blink Condition (B), and Display Size (S).

Most importantly for present purposes, the interaction between blink condition and display size was significant, but the three-way interaction between task, blink condition, and display size was not. Blinking affected short-term memory capacity in all three tasks only at the largest display size; averaged across tasks, blinking reduced short-term memory capacity by 0.65 items (95% confidence interval for the difference between two means = ±0.56). Thus the results of Experiment 1 indicate that eye blinks interfere with the contents of short-term memory.

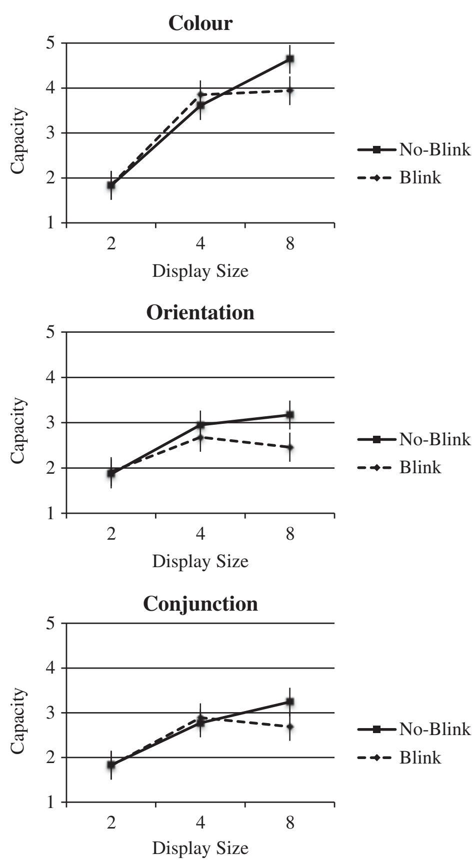

Figure 1. Memory capacity (number of items remembered) for no-blink and blink trials as a function of display size in the colour, orientation, and conjunction change detection tasks in Experiment 1. Error bars denote standard error.

EXPERIMENT 2

Although the results of Experiment 1 show that blinks reduce short-term memory capacity, the viewing conditions employed in that experiment were rather dissimilar to those that exist in the real world; that is, as in the example mentioned in the Introduction in which someone fails to notice that their computer display has changed if the change takes place during an eye blink. To simulate more natural viewing conditions as closely as possible, a blink-contingent procedure was used in Experiment 2 to control stimulus presentation on blink trials: Participants viewed the initial display until they initiated an eye blink, and then the test display was presented during the blink while the eyes were closed and thus was present on the screen when the eyes reopened. The question of interest was whether blinks would still reduce

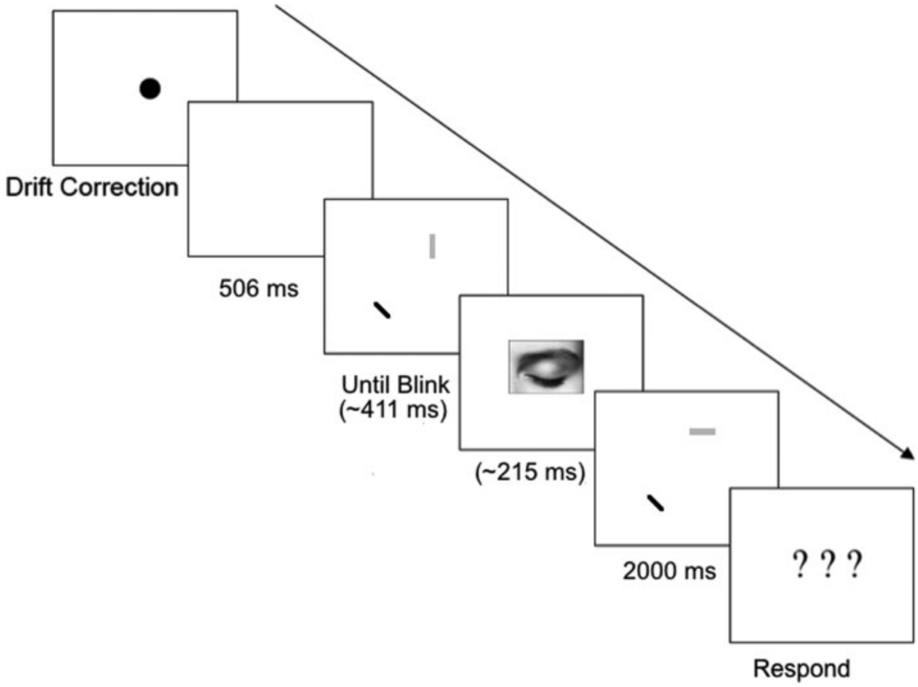

Figure 2. Experiment 2 sequence of events on blink trials in the orientation change detection task with a display size of two items. On no-blink trials the initial display was presented for 506 ms and the retention interval was 200 ms.

short-term memory capacity if the stimulus change took place during an eye blink.

Method

Participants. A total of 12 students from the University of Illinois community were recruited for this experiment. Participants reported normal or corrected to normal vision and were naïve as to the purpose of the experiment. They received payment for participating in a single 90-minute session. None of them had participated in the first experiment.

Apparatus. The apparatus was the same as in Experiment 1, but in Experiment 2 the output of the eyetracker was analysed online to detect eye blinks. 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 eye blink was defined as a period of missing pupil for at least 6 consecutive ms, and this event triggered the presentation of the test display on blink trials.

Procedure. The procedure was identical to Experiment 1, with the following exceptions. On no-blink trials the initial display was presented for 506 ms, but the retention interval was reduced to 200 ms to approximate the duration of an eye blink. On blink trials (see Figure 2) the initial display was presented until the participant initiated an eye blink; when the blink was detected (i.e., when the pupil was covered for 6 consecutive milliseconds) the test display was presented while the eyes were closed and was visible on the screen when the eyes reopened. Average blink latency (and hence initial display duration on blink trials) was 411 ms (SD = 189 ms) and average blink duration was 215 ms (SD = 104 ms). As in Experiment 1, the test display was presented for a maximum of 2000 ms and participants indicated (by pressing one of two buttons on the game controller) whether the test display was identical or different from the initial display. Mean reaction time to respond same or different to the test display was 722 ms on no-blink trials and 813 ms on blink trials.

Results

No-blink trials in which a participant blinked before the onset of the test display (1.4% of no-blink trials) were excluded from analysis. Blink trials with blink latencies less than 200 ms (3.1% of blink trials) or blink latencies greater than 1200 ms

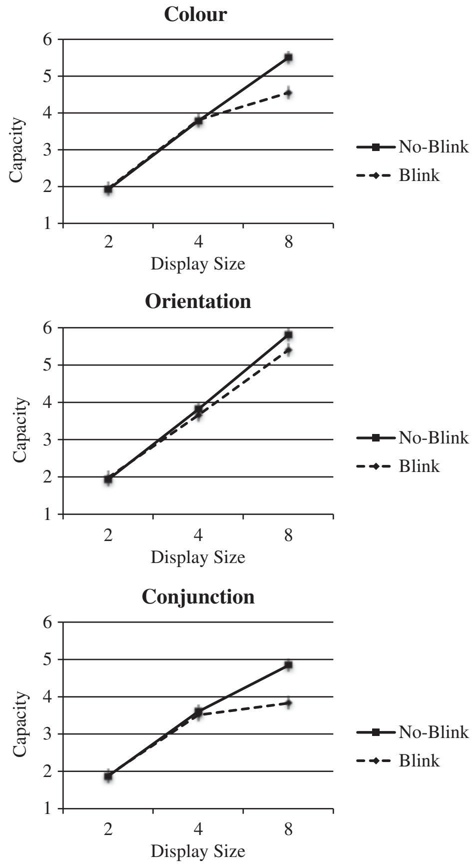

Figure 3. Memory capacity (number of items remembered) for no-blink and blink trials as a function of display size in the colour, orientation, and conjunction change detection tasks in Experiment 2. Error bars denote standard error.

(2.9% of blink trials) were also excluded from analysis. Finally, trials in which an inappropriate response button (neither *same* nor *different*) was pressed (0.5% of all trials) were also excluded.

As in Experiment 1, percent correct on same and different trials was converted into estimates of the number of items held in memory (K). Capacity as a function of display size for the three different tasks under blink and no-blink conditions is shown in Figure 3. Capacity was higher in this experiment than in Experiment 1, most likely because the retention interval was shorter (200 ms as opposed to 900 ms).

The capacity estimates (K) were analysed in a three-way ANOVA with task, blink condition, and display size as repeated-measures factors. The results are summarised in Table 2. Scheffé simultaneous confidence intervals were constructed based on the error term for each effect to examine comparisons of interest. The main effect of task was significant: Short-term memory capacity was

TABLE 2
Summary of ANOVA, Experiment 2

Effect	*df*	*F*	*p*	*MSe*
T	2, 22	6.26	< .01	0.765
B	1, 11	5.48	< .05	0.777
S	2, 22	94.84	< .001	1.800
T × B	2, 22	0.35	> .70	0.501
T × S	4, 44	5.28	< .001	0.515
B × S	2, 22	5.90	< .01	0.607
T × B × S	4, 44	0.69	> .60	0.400

Factors are Task (T), Blink Condition (B), and Display Size (S).

higher in the feature memory tasks (colour = 3.58 items, orientation = 3.76 items) than in the conjunction memory task (3.26 items; 95% confidence interval for the difference between two means = ±0.27). It was also higher on no-blink trials (3.67 items) than on blink trials (3.39 items). The main effect of display size was also significant: Capacity increased as display size increased, 95% confidence interval = ±0.59. The interaction between task and display size was significant: The effect of display size was larger in the orientation (3.66 item increase) memory task than in the conjunction task (2.46 item increase; 95% confidence interval for the interaction = ±0.67).

Most importantly for present purposes, the interaction between blink condition and display size was significant, but the three-way interaction between task, blink condition, and display size was not. Blinking affected short-term memory capacity in all three tasks only at the largest display size; averaged across tasks, blinking reduced short-term memory capacity by 0.79 items (95% confidence interval for the difference between two means = ±0.48), from 5.38 items to 4.59 items. This reduction is similar in magnitude to the decrement found in Experiment 1. Thus the results of Experiment 2 show that eye blinks interfere with the contents of short-term memory even under temporal conditions that match those of normal viewing.

EXPERIMENT 3

The results of the first two experiments indicate that eye blinks interfere with the contents of short-term memory. One might wonder whether the interference that was observed was not caused by the eye blink per se, but rather was a general dual-task cost caused by requiring participants to make a secondary response. Experiment 3 was designed to investigate whether or not motor responses other than eye blinks interfere with the contents of short-term memory. This was examined by requiring participants to make an irrelevant button press (instead of an eye blink) on some trials. If any motor response interferes with the contents of short-term memory, then the results of Experiment 3 should replicate those of Experiment 1. In contrast, there should be no difference in performance between the button-press and no-button-press conditions of Experiment 3 if the interference observed in the first two experiments was due to eye blinks per se.

Method

Participants. A total of 12 students from the University of Illinois community were recruited for this experiment. Participants reported normal or corrected to normal vision and were naïve as to the purpose of the experiment. They received payment for participating in a single 30-minute session. None of them had participated in the first two experiments. Because no effect of task (i.e., colour, orientation, or conjunction) was found in the first two experiments, each participant completed only the conjunction task.

Stimuli and apparatus. The stimuli and apparatus for Experiment 3 were identical to those described for Experiment 1. Participants made their button press responses with a Microsoft Sidewinder digital game controller interfaced with the computer.

Procedure. Trials in the no-button-press condition were identical to the no-blink trials of Experiment 1. Button-press trials followed the same course of events as the blink trials used in Experiment 1 but, instead of being instructed to blink, participants in Experiment 3 were instructed to press a button with their right thumb during the retention interval.

Results

No-button-press trials in which a participant pressed a button before the onset of the test display (0.3% of no-button-press trials) were excluded from analysis. Button-press trials in which a participant did not press the response button during the retention interval (5.5% of button-press trials) were also excluded from analysis. Mean button-press latency (measured from the onset of the initial display) was 765 ms (*SD* = 124 ms) and mean button-press duration was 198 ms (*SD* = 88 ms). Thus, on average, the button press started 259 ms after the offset of the initial display and ended 443 ms before the onset of the test display. Mean reaction time to respond same or different to the test display was 898 ms on no-button-press trials and 878 ms on button-press trials.

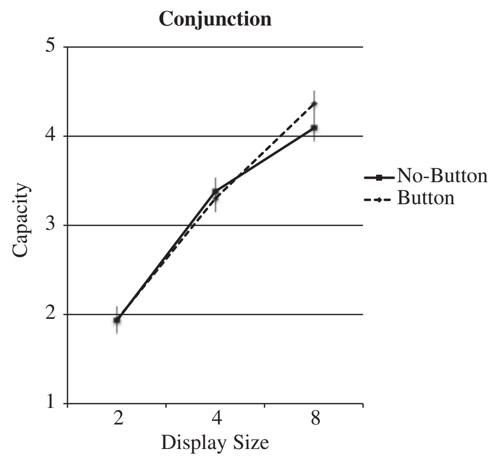

Figure 4. Memory capacity (number of items remembered) for no-button-press and button-press trials as a function of display size in the conjunction change detection task in Experiment 3. Error bars denote standard error.

As in Experiments 1 and 2, percent correct on same and different trials was converted into estimates of the number of items held in memory (K). Capacity as a function of display size is shown in Figure 4.

The capacity estimates (K) were analysed in a two-way ANOVA with button-press condition and display size as repeated-measures factors. The main effect of display size was significant, $F(2, 22) = 44.05$, $MSe = 0.726$, $p < .001$: Capacity increased as display size increased from 2 (K = 1.94) to 4 (K = 3.34) to 8 (K = 4.22) items, 95% confidence interval for the difference between two means = ± 0.37.

No other main effects or interactions were significant, all $F < 1.0$. Most importantly for present purposes, the interaction between button condition and display size was not significant, $F(2, 22) = 0.749$, $MSe = 0.269$, $p > .45$. Memory capacity at the largest display size was actually slightly (but not significantly; 95% confidence interval for the difference between two means = ± 0.55) higher under button-press (K = 4.36) than under no-button-press (K = 4.09) conditions. Thus the results of Experiment 3 show that pressing a button during the retention interval had no effect on short-term memory capacity. This suggests that the reduction in short-term memory capacity found in Experiments 1 and 2 was not due to a general dual-task cost, but rather was specific to eye blinks.

DISCUSSION

The results of the first two experiments show that eye blinks reduce short-term memory capacity, both for feature stimuli and for conjunction stimuli. However, the effect is fairly small in absolute terms, corresponding to approximately 0.6–0.8 items. This small effect may seem somewhat contrary to the results of O'Regan et al. (2000), who found that changes in photographs of naturalistic scenes during eye blinks were frequently undetected, even when participants were fixating the changed location before and after the eye blink. However, there are many differences between the current study and the O'Regan et al. study that make comparison difficult. O'Regan et al. used complex photographs with many objects in them, and a variety of changes were possible, and participants were not told that changes would occur during eye blinks. In contrast, in the present study the stimuli were simple, limited in number, and participants were told what kind of change might occur and when they should blink their eyes. It is possible that participants in the O'Regan et al. study also remembered approximately four items across an eye blink but, because there were so many items in the display, many changes were missed. This conjecture is perhaps supported by the fact that changes to items of central interest were detected better than changes to items of marginal interest in the O'Regan et al. study, if one assumes that items of central interest were more likely to be attended to and encoded into short-term memory. Given the complexities of the O'Regan et al. study it is not possible to quantify the effects of eye blinks on short-term memory capacity based on their results, whereas that was the purpose of the present study.

The fact that eye blinks affected short-term memory capacity only at the largest display size indicates that blinking reduces the maximum short-term memory capacity rather than having a proportional effect at each display size. Display sizes of 2 and 4 were below this maximum capacity, so blinking had no effect on performance at these display sizes (i.e., in essence there was a ceiling effect at the smaller display sizes).

Whereas O'Regan et al. (2000), Higgins et al. (2009), and the current study found that eye blinks interfere with short-term memory, Thomas and Irwin (2006) did not. This is most likely due to a lack of statistical power in the Thomas and Irwin study. There actually was a small difference (2.5%) in accuracy between no-blink and blink conditions at long cue delays in the Thomas and Irwin study but it was not statistically significant.

The results of Experiment 3 showed that pressing a button during the retention interval did not interfere with short-term memory capacity, indicating that the interference caused by eye blinks in the first two experiments was not a general dual-task cost. This finding may seem at odds with various other studies that have found dual-task costs in short-term memory (e.g., Allen, Baddeley, & Hitch, 2006; Morey & Bieler, 2012; Morey & Cowan, 2005; Stevanovski & Jolicoeur, 2007). The difference is that the button-press task did not require any processes of discrimination or identification and involved no cognitive load beyond remembering to press a button during the retention interval, a very routine task, whereas the studies finding dual-task costs did involve discrimination, identification, or a cognitively demanding secondary task (e.g., backward counting). The interesting thing about eye blinks is that they too would appear to be routine and to involve minimal cognitive load, but they caused a reduction in short-term memory capacity while button-presses did not. This is presumably due to the fact that eye blinks, like saccadic eye movements, cause a reallocation of visual attention (Irwin, 2011), and this reallocation may interfere with rehearsal mechanisms that also rely on visual attention (Awh & Jonides, 2001). Thus the results of the present experiments provide additional support for the hypothesis that visual-spatial attention is important for the maintenance of information in short-term memory.

In conclusion, consistent with everyday experience and with the results of some prior research, eye blinks interfere with short-term memory by reducing its capacity by approximately 0.6–0.8 units. Although this might seem like a small effect in absolute terms, it represents a decrement of 15–20% if one assumes that the capacity of short-term memory is 4 items (Cowan, 2001).

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