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Change Detection and Change Blindness in Pigeons (Columba livia)

Walter T. Herbranson, Yvan T. Trinh, Patricia M. Xi, Mark P. Arand, Michael S. K. Barker, and Theodore H. Pratt

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Whitman College

Change blindness is a phenomenon in which even obvious details in a visual scene change without being noticed. Although change blindness has been studied extensively in humans, we do not yet know if it is a phenomenon that also occurs in other animals. Thus, investigation of change blindness in a nonhuman species may prove to be valuable by beginning to provide some insight into its ultimate causes. Pigeons learned a change detection task in which pecks to the location of a change in a sequence of stimulus displays were reinforced. They were worse at detecting changes if the stimulus displays were separated by a brief interstimulus interval, during which the display was blank, and this primary result matches the general pattern seen in previous studies of change blindness in humans. A second experiment attempted to identify specific stimulus characteristics that most reliably produced a failure to detect changes. Change detection was more difficult when interstimulus intervals were longer and when the change was iterated fewer times.

Keywords: change blindness, change detection, pigeons, attention, perception

Attention is a fundamental cognitive process in many animals, allowing for the allocation of cognitive resources to important areas of the local environment while suppressing input from other areas. In that sense, flexible control of attention would seem to be adaptive in that it allows for preferential processing of those locations that contain items relevant to survival, such as food, predators, and conspecifics. An animal that can regulate its attention from moment to moment presumably would hold an advantage over one that cannot and must process all input channels equally.

Despite the importance of attention, human cognitive psychology has demonstrated that it is not always flawless, and people often fail to notice even prominent features of their environment. For example, Simons and Levin (1998) had confederates approach individuals on a college campus and ask for directions. During the ensuing conversation, workers walked between the participant and the confederate carrying a door that briefly interrupted visual contact. Most participants failed to notice that their conversation partner had been replaced during the interruption. Recent research has shown that such failures of attention may be more common than one would expect (see Simons & Ambinder, 2005, for a review).

Although Simons and Levin's (1998) striking demonstration shows that humans may miss prominent details in a real-world setting, it does not specify the kinds of situations in which it will happen. That is to say, as with any experiment, high external validity sacrifices a corresponding degree of internal validity. Tightly controlled laboratory experiments have helped to delve further into such phenomena. For example, Rensink, O'Regan, and Clark (1997) developed a task in which photographic images were edited to remove a feature. When the original and modified images were presented in alternation, the difference was quickly and easily seen by participants. However, if brief blank fields were inserted between the alternating presentations, producing a flickering image, the change became considerably more difficult to identify. This failure to identify the location of the change is a prototypical example of change blindness. In both cases, the original and modified images themselves were visible for the same amount of time. The difference was in the timing of the displays (specifically, the presence or absence of a delay between presentations). Thus, the difference in accuracy was not due to exposure duration but rather to a participant's ability to compare two sequentially presented images. If the two images were temporally contiguous, the change was quickly spotted. Disruption of that contiguity reliably impaired performance.

Experiment 1

Like humans, pigeons demonstrate an impressive degree of attentional control, and in many ways pigeons' attention closely mirrors human attention. For example, pigeons can direct their attention to different locations within a stimulus display in ways that resemble human spatial attention (Shimp & Friedrich, 1993). Likewise, pigeons can direct their attention either to the local elements of a display or to the global configuration of those elements (Fremouw, Herbranson, & Shimp, 1998). Pigeons can also selectively attend to the relevant dimensions of a stimulus display while ignoring irrelevant ones (Herbranson, Fremouw, & Shimp, 1999).

Given these parallels between attentional control in pigeons and humans, it may be that pigeons also demonstrate change blindness. If they do, then it would indicate that change blindness occurs in two species that are only distantly related. On the other hand, if pigeons do not demonstrate change blindness, it might be the case that change blindness is a consequence of some element of human attention or vision that is not shared with pigeons.

Pigeons would appear to possess the basic cognitive mechanisms required to test for change blindness. In particular, they can be trained to search for and notice differences between sequentially presented visual displays. Cook, Kelly, and Katz (2003) trained pigeons on a successive same/different task in which they viewed alternating presentations of two photographic images. Pecks were reinforced only if the two images were the same. Birds learned the task and eventually showed above-chance discrimination by the presentation of the second image, the earliest point possible. Furthermore, pigeons can learn to search for and selectively peck a localized change within a larger visual display. Wright et al. (2010) created a change detection task in which pigeons had to peck one of two colored circles in a test array, and responses on the circle that was not the same color as in the previously displayed sample were reinforced. Their results indicated that pigeons could learn to reliably detect localized color changes in a changing display, and they could do so even when successive displays were separated by a time delay.

The present experiment attempted to investigate change blindness in pigeons by creating an analog of Rensink et al's (1997) flicker paradigm. Pigeons were presented with alternating displays that differed by the presence of one specific feature, either with or without an interstimulus interval (ISI). If pigeons are susceptible to change blindness, the results should show better change detection if there is no ISI than if there is an ISI. In addition, if change detection requires an animal to actively search the display for a change, then we should expect better change detection when given more time to do so. Thus, the results should indicate better change detection accuracy when displays are presented for a greater number of alternations.

Method

Animals.   Six White Carneaux pigeons (*Columba livia*) were purchased from Double-T Farm (Glenwood, IA). Each was maintained at 80–85% of free-feeding weight to approximate the condition of healthy wild birds (Poling, Nickel, & Alling, 1990). Birds were housed in individual cages in a colony room with a 14:10-h light:dark cycle and had free access to water and grit. All six had previous experience with a serial response time task (Herbranson & Stanton, 2011).

Apparatus.   Four identical BRS/LVE operant chambers were used. Each had three circular response keys (2.5 cm in diameter) located in a horizontal row in the front wall and a food hopper located directly below the center key. A houselight located on the front wall, directly above the center key, was illuminated for the duration of each experimental session.

Stimuli.   Stimuli consisted of straight white lines back-projected onto each response key using stimulus projectors (Industrial Electronic Engineers, Van Nuys, CA) that had been retrofitted with LED light sources (Martek Industries, Cherry Hill, NJ).[1] Each of the three keys was capable of displaying up to eight

radial lines, with each line spanning the entire diameter of the key. The eight possible lines on each key appeared at evenly spaced orientations corresponding to 0.0°, 22.5°, 45.0°, 67.5°, 90.0°, 112.5°, 135.0°, and 157.5° from vertical.[2] On each trial, a base stimulus was generated according to the following parameters: each of the eight lines on each of the three keys independently had a .5 chance of being present and a .5 chance of being absent. Consequently, each stimulus could consist of anywhere from 0 to 24 lines across the three keys (0–8 per key). A modification of that base stimulus was then generated by reversing the display status of exactly 1 of the 24 possible lines. If the line to be reversed was present in the base display, then it was not present in the modified display. Conversely, if it was not present in the base display, then it was present in the modified display. The modified line feature was selected randomly, and it was equally likely to occur on any of the three keys and in any of the eight orientations.

Each trial consisted of alternating 250-ms presentations of the original and modified displays. The 2 displays were each presented 1, 2, 4, 8, or 16 times (randomly determined on each trial with $p = .2$ for each). Each presentation of the original display was followed by the modified display, and each presentation of the modified display was followed by either the original display or a trial-terminating display consisting of three white key lights (if and only if it was the final repetition of the trial).

On one half of all trials, the transition from an original to a modified display and vice versa was continuous, with no time delay. That is, once stimulus presentation began, there was no time when one of the two displays (base or modified) was not present on the response keys until the end of the trial. On the other half of the trials, there was a 250-ms ISI between each subsequent stimulus display. During the ISI, the keys were completely dark and no lines were visible. Thus, on trials with an ISI, the same number of repetitions took twice as long because each 250-ms stimulus presentation was followed by an ISI of the same duration. Figure 1 summarizes one iteration from a trial with a 250-ms ISI. A trial with no ISI would simply omit the empty displays in the second and fourth positions.

Procedure.   There were 120 trials in a daily experimental session, gradually increased from 10 over the first 15 days of the experiment. Each trial consisted of a 5-s intertrial interval (ITI), a stimulus presentation, a choice response from among the three keys, and reinforcement if the response was correct. The houselight remained on throughout each session. During the 5-s ITI, the computer generated an original and modified display, as specified above, and selected the number of repetitions to present and whether or not there would be an ISI. During stimulus presentation, responses on the pecking keys had no programmed consequences, and no pecks were recorded. After the display, all three keys were uniformly illuminated with white light, and the first

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[1] LED bulbs were necessary to ensure accurate presentation times for the stimuli, particularly in Experiment 2. A photometer indicated that the LEDs in the stimulus projectors reached peak brightness within 30 μs after a signal was sent from the computer. Light offset was slightly slower, but it was still very fast, reaching complete darkness within 100 μs. By comparison, incandescent bulbs have rise and fall times of 100–300 ms, making rapid stimulus presentation impossible.

[2] Because lines span the entire diameter of a key, these same lines also correspond to 180.0°, 202.5°, 225.0°, 247.5°, 270.0°, 292.5°, 315.0°, and 337.5°, respectively.
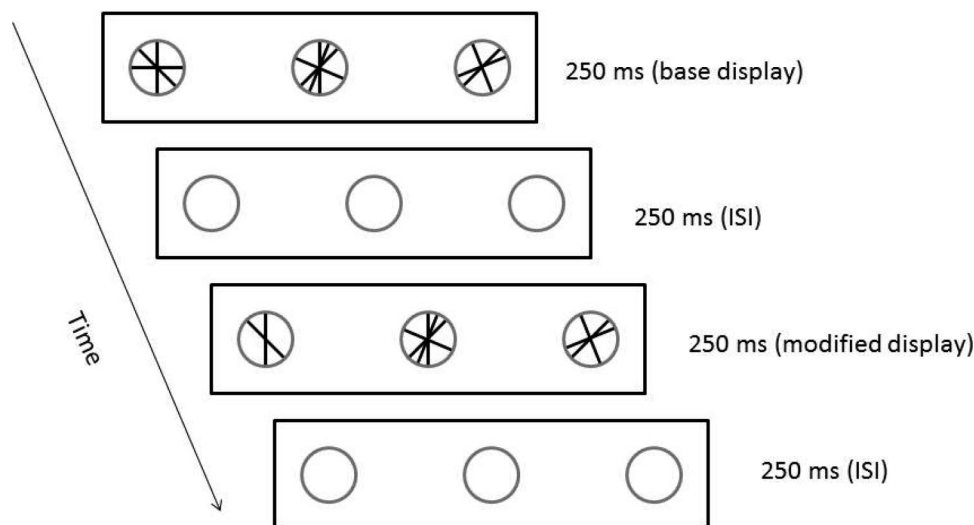
Figure 1. Structure of a trial in Experiment 1. The base and modified displays consist of identical elements with one exception (in this example, the horizontal line on the left key). Half of all trials included an ISI after each display (shown). The other half omitted the ISIs (second and fourth frames).

peck on any key was automatically recorded. If that peck corresponded to the location of the change, then a bird was presented with approximately 3-s access to mixed grain (times varied slightly between birds to maintain individual running weights). If a bird's response corresponded to either of the other two locations, then it was followed by a 10-s error signal during which the houselight flashed on and off every 0.5 s. After either reinforcement or the error signal, the experiment continued along to the next trial.

Because birds had previous experience with these same operant chambers, no pretraining was necessary. Birds were run for a total of 165 days, until they had reached a relatively stable level of performance, as estimated by the experimenters.[3]

Results

Accuracy. Figure 2 displays mean accuracy over the final 10 days of the experiment as a function of the two independent variables: trial type and number of repetitions. The figure shows that as expected, accuracy was better for trials with no ISI and for trials with more repetitions. A 2 (trial type: ISI, no ISI) × 5 (repetition: 1, 2, 4, 8, 16) repeated-measures analysis of variance (ANOVA) confirms these observations. There was a main effect of trial type, $F(1, 9) = 152.40$, $p < .001$, $\eta^2 = .93$, indicating that accuracy was better on trials with no ISI (light bars; $M = 58.13$) than on trials with an ISI (dark bars; $M = 38.12$). There was also a main effect of number of repetitions, $F(4, 36) = 40.22$, $p < .001$, $\eta^2 = .80$, in which more repetitions yielded higher accuracy. Finally, there was an interaction between trial type and repetition, $F(4, 36) = 37.58$, $p < .001$, $\eta^2 = .77$, indicating that the effect of trial type was more pronounced when there were more repetitions.

Recall that our operational definition of change blindness relies on a comparison between trials with and without an ISI. Specifically, change blindness corresponds to impaired accuracy on trials with an ISI relative to trials without. Therefore, to test for change blindness, we compared each pair of means (ISI and no-ISI) having the same number of repetitions using a series of paired-sample t tests. There was a significant difference favoring no-ISI trials at repetitions of 2, $t(9) = 4.62$, $p = .001$, $d = 1.46$, 4, $t(9) = 9.66$, $p < .001$, $d = 3.06$, 8, $t(9) = 14.79$, $p < .001$, $d = 4.68$, and 16, $t(9) = 10.25$, $p < .001$, $d = 3.24$. There was no difference between trials with and without ISIs of a single repetition, $t(9) = 0.173$, $p = .866$, $d = 0.05$. Significant differences are denoted in Figure 2 by asterisks.

Note that although accuracy on trials with an ISI was considerably lower than on trials without, birds were still better than chance (33%) on ISI trials of 2, 8, and 16 repetitions. Thus, as shown by the 95% confidence intervals (error bars) in Figure 2, the only trial types for which accuracy was not reliably greater than chance were ISI and no-ISI trials of a single repetition and ISI trials of four repetitions.

Position Bias. On difficult tasks, pigeons sometimes develop a position bias in which responses are not evenly distributed across available options. The present task is no exception, and each bird allocated a preponderance of its pecks to one or two of the three response keys. However, the strength of the position bias was not constant across trial types. Bars in Figure 3 show the distribution of responses across the three keys for trials of different lengths over the final 10 days of the experiment. Because preferences differed between birds, the first, second, and third preferred keys were identified separately for each bird as the keys on which the

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[3] Each of the three keys can display 2^8 or 256 different stimuli. Across the three keys, that allows for 16,777,216 unique displays. Each of those stimulus displays can be modified as described by adding or deleting 1 of the 24 radial lines to produce 402,653,184 different pairings of original and modified displays. Each of those pairs of displays may in turn appear either with or without an ISI, yielding a grand total of 805,306,368 unique trial types (ignoring different numbers of repetitions). At 120 trials per day, a pigeon would have seen the entire stimulus set of slightly less than 1 billion displays only after 18,385 years of continuous daily training, assuming no stimulus repetitions. Memorization would thus appear to be a difficult strategy to implement effectively.
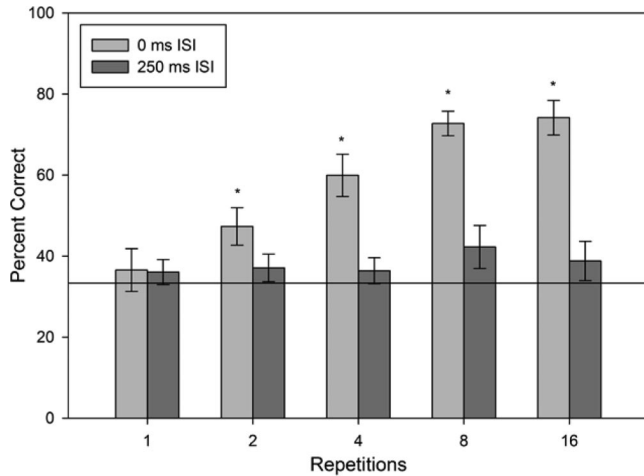
Figure 2. Accuracy over the final 10 days of Experiment 1 as a function of repetitions and ISI duration. Asterisks indicate reliable differences between trials with and without ISIs for each number of repetitions. Error bars depict 95% confidence intervals.

first- second- and third-most responses were made. Note that the position bias was strongest on shorter trials and became progressively weaker as repetitions increased. On the longest trials (16 repetitions), a bias was still present, but it was considerably weaker. To see if change detection accuracy changed along with this dissipating position bias, we computed the likelihood of detecting changes on each of the three keys at each repetition value (lines in Figure 3). If birds were not influenced by the location of the change (i.e., were responding randomly within the constraints of their position bias), then the percent of identified changes presented on each key should approximate the percent of responses allocated to that key. On the other hand, the ability to consistently detect the locations of changes would cause the percentage of correctly identified changes on a key to exceed the percentage of responses allocated to that key.

An inspection of Figure 3 reveals that pigeons were close to chance on trials that consisted of a single repetition because accuracy on each key approximately matched the proportion of responses on each key. This was true regardless of key preference. Although pigeons correctly pecked approximately 60% of the changes displayed on their preferred key, they were able to do so only because they pecked that key on a similarly high proportion of trials. As the number of repetitions increased, accuracy on all three keys increased steadily and quickly eclipsed a value that could be accounted for solely by the corresponding position bias. Note that the percentage of correctly identified changes on the first- and second-preferred keys increased as their bias shifted away from those locations. Note also that accuracy on the least-preferred key was below chance until four repetitions, and it was not above chance until eight repetitions. Birds apparently could identify changes in either of two locations on short trials as long as there was more than one repetition. On longer trials, their ability to accurately identify the location of changes expanded to encompass all three keys.

Discussion

Pigeons were better at detecting changes if there was no ISI between successive displays than if there was a 250-ms ISI. This parallels the phenomenon known as change blindness in previous experiments using human participants. For example, when two depictions of a visual scene that differ by a single feature are alternated with no intervening ISI, humans almost instantaneously see the difference. On the other hand, when an ISI is present, detection of the change is slower and involves an active search that requires time and attentional focus (Rensink et al., 1997). Although the stimuli used in the current experiment are considerably simpler than the photographic stimuli that have typically been used in change blindness research, the result of central interest is the same: birds were more likely to see the change when there was no ISI. When there was an ISI that interrupted the continuity between the two displays, birds apparently had great difficulty identifying the location of the change.

A second factor that influenced accuracy was the number of repetitions. In particular, if birds had more opportunities to identify the change, then their ability to do so was enhanced. This result is also consistent with the results of previous experiments using the flicker paradigm with human participants. Humans perform a self-terminating search that ends when they identify the change (provided they are given sufficient time to locate the change; Rensink et al., 1997). Subsequently, the change remains obvious. Birds could similarly be engaging in an active search that terminates when the change is identified. Not only was accuracy better on longer trials, but the birds' effective search area increased with the number of presented repetitions. On long trials (eight or more repetitions), pigeons were better than chance at pecking changes displayed on any of the three keys. On shorter trials, they were
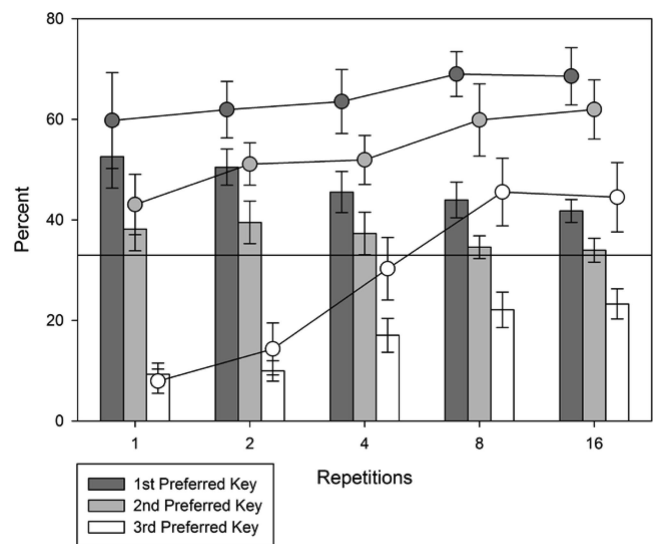

Figure 3. Analysis of position bias across different numbers of repetitions and the resulting changes in performance over the final 10 days of Experiment 1. Vertical bars represent the percentage of choices on the first, second, and third preferred keys. Key preferences were different for each bird and were determined by the total number of choices on each key for each individual bird. Lines represent the percentage of correctly detected changes presented on each key. Error bars depict 95% confidence intervals.

only able to reliably identify changes on two of the three keys, perhaps because the brevity of those trials did not afford them sufficient time to inspect all three locations.

These results build upon similar experiments with pigeons. Cook et al.'s (2003) successive same/different task was similar in that pigeons learned to compare two alternating displays and respond based on that comparison. However, note that difference and change are, at least in theory, not the same thing (see Rensink, 2002). Change makes reference to a single entity that is modified across time whereas difference makes reference to a comparison between two separate entities that may or may not exist simultaneously. Thus, a same/different task (in which the compared images are vastly different) and a change detection task such as the present experiment (in which most features present in one display are also present in its alternating partner) might be importantly (and appropriately) different. Therefore, an understanding of both concepts (change and difference) will be necessary for a complete understanding of attention in pigeons.

Finally, although accuracy in this experiment was not especially high (particularly on trials with an ISI), it was reliably greater than chance performance of 33%. This was even the case for trials with an ISI. Therefore, it cannot be the case that pigeons simply interpreted ISI trials as displaying multiple changes across all three keys (i.e., the transitions from stimulus display to ISI and vice versa) because such an interpretation would have led to chance performance. The low accuracy on ISI trials may have been a consequence of the line orientation stimuli, which apparently yielded a particularly difficult task. Thus, a lengthy ISI by itself does not render change detection prohibitively difficult.

Experiment 2

Although pigeons' accuracy on trials with an ISI in Experiment 1 was reliably greater than chance, it was not much greater. The ISI trials were apparently very difficult for pigeons, especially when compared with trials having no ISI. As a result, there was little variability among ISI trials presented for different numbers of iterations, and that lack of variability may have disguised a potential repetition effect. It may be that additional repetitions beyond the maximum value of 16 used in Experiment 1 would yield correspondingly higher accuracy. However, repetition is only one potential means of increasing accuracy.

Another way to increase accuracy may be to manipulate the duration of the ISI. For example, Pashler (1988) had participants view two successive arrays of alphanumeric characters that were identical except for one character. Changing the duration of the displays themselves had little effect on participants' ability to identify the change, but changing the duration of the ISI between displays did. In particular, there was a sharp increase in change detection at the shortest ISIs (34 ms).

In Experiment 1, the duration of the ISI was relatively long (250 ms, the same as the duration of the displays themselves). We expect that as ISI duration is shortened, accurate detection of changes will be more likely because of increased temporal proximity between the original and modified stimulus displays.

Method

Animals. The same six pigeons that were in Experiment 1 were also in Experiment 2.

Apparatus. The same four BRS/LVE operant chambers that were used for Experiment 1 were also used for Experiment 2.

Stimuli. Stimuli were exactly as described in Experiment 1 with the following exception. Over the 80 days of the experiment, the length of the ISI was shortened by approximately 50% every 10 days. This produced seven blocks having ISIs of 250, 125, 60, 30, 15, 7, and 3 ms. After the final 3-ms block, there was a replication of the initial 250-ms block.

Procedure. The procedure was the same as in Experiment 1 with the exception of the different ISI lengths. During each 10-day block, half of the trials had an ISI of the prescribed length and half of the trials had no ISI.

Results

Figure 4 shows mean accuracy during each 10-day block as a function of the trial type and ISI duration in Experiment 2. Note that accuracy is better than chance (33%) for every trial type, although there is considerable variability between means for the different trial types. To characterize the effects of these two independent variables, a 2 (trial type: ISI, no ISI) × 8 (ISI: 250, 125, 60, 30, 15, 7, 3, 250) ANOVA was computed on accuracy. As in Experiment 1, accuracy was better on trials with no ISI (light bars; $M = 57.81$) than on trials with an ISI (dark bars; $M = 43.39$), $F(1, 9) = 470.69$, $p < .001$, $\eta^2 = .97$. As expected, accuracy was better on trials with shorter ISIs, $F(7, 63) = 70.55$, $p < .001$, $\eta^2 = .87$. Finally, there was a significant interaction, $F(7, 63) = 54.28$, $p < .001$, $\eta^2 = .83$, indicating that the effect of trial type was more pronounced at longer ISIs.

Although the overall improvement in accuracy at shorter ISIs is confounded with the amount of training (left to right in Figure 4, excluding the final pair of bars), notice that the final replication of the 250-ms ISI condition (right-most bars) produced results that are nearly identical to the initial 250-ms condition (left-most bars). This similar performance indicates that ISI is a more plausible explanation for differences in accuracy than the additional training.
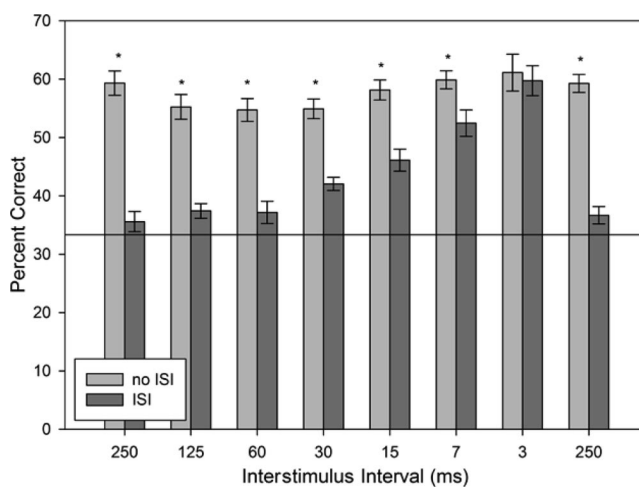

Figure 4. Accuracy of pigeons in Experiment 2 as a function of ISI duration and trial type. Asterisks indicate significant differences between trials with and without ISIs for each ISI duration. Error bars depict 95% confidence intervals.

Recall that our operational definition of change blindness is the difference between trials with and without an ISI and corresponds to the differences between pairs of bars in Figure 4. Although Figure 4 shows that ISI duration had a systematic effect on change blindness, note that it collapses across different numbers of repetitions, another factor that is likely to influence whether or not a change is detected. Figure 5 displays change blindness (again, the difference in accuracy between trials with and without an ISI) as a function of ISI duration and number of repetitions. The figure clearly shows that repetition also influenced accuracy in an orderly fashion. To clarify how, a 5 (repetition: 1, 2, 4, 8, 16) × 7 (ISI: 250, 125, 60, 30, 15, 7, 3) repeated-measures ANOVA was computed on our measure of change blindness (again, change blindness was calculated as accuracy on trials with no ISI minus accuracy on trials with an ISI). There was a main effect of repetitions indicating that change blindness was more pronounced on trials with more repetitions, $F(4, 36) = 139.10$, $p < .001$, $\eta^2 = .88$. There was a main effect of ISI indicating that change blindness was more pronounced at longer ISI values, $F(6, 54) = 37.85$, $p < .001$, $\eta^2 = .75$. There was a significant interaction between repetition and ISI length indicating that repetition had a greater effect on trials with longer ISIs, $F(24, 216) = 4.94$, $p < .001$, $\eta^2 = .33$.

Discussion

Experiment 2 explored one way to improve performance on a change detection task and further defined the conditions under which change blindness occurs in pigeons. Specifically, the difference between ISI and no-ISI trials gradually decreased as the ISI was shortened. The reduction was caused by an increase in accuracy on ISI trials to meet the uniformly high accuracy of no-ISI trials. At the shortest ISI tested (3 ms), there was no difference and performances on the two trial types were roughly equivalent.

As did Experiment 1, the present experiment builds on the results of previous investigations of change detection in pigeons.
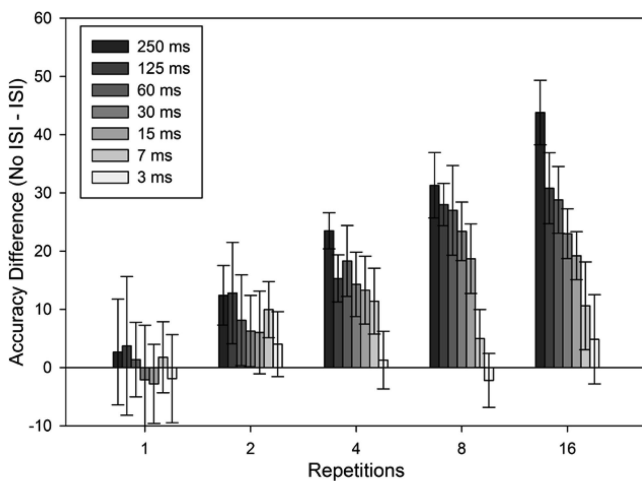

Figure 5. Change blindness as a function of stimulus repetition and ISI duration for pigeons in Experiment 2. Change blindness is computed as accuracy on trials with no ISI minus accuracy on trials with an ISI. Error bars depict 95% confidence intervals.

Wright et al.'s (2010) pigeons also learned a change detection task, but they performed with greater accuracy even with longer ISIs (up to 6,400 ms, compared with the 250 ms in the present experiments). This considerable difference in overall accuracy might be grounded in the details of the two procedures. In the methodology used here, any of 24 lines in the stimulus display could change on any trial. In contrast, the change in the procedure of Wright et al (2010) always involved a single attribute (color), appearing in either of two locations. It may be that color is a more salient stimulus dimension than the line elements used here or that the use of a single stimulus attribute in a more limited set of possible locations made change detection easier (or both). Thus, although accuracy on ISI trials in the present experiment was limited, previous research might point toward additional means for increasing overall accuracy and perhaps producing an even more robust change blindness effect.

In addition to comparing these results with previous change detection research in pigeons, one should also consider how those results compare with those of previous change blindness research in humans. Rensink, O'Regan, and Clark (2000) used the flicker paradigm to investigate the importance of the number of elements in a display and found that there was a capacity of approximately five items that could be maintained across an ISI. If the processes underlying pigeon change detection parallel those underlying human change detection and there is a limited attentional capacity, then Rensink et al.'s (2000) result might account for the relative difficulty of the task presented here, which involved all of 24 candidate elements (an average of 12 on any given trial) distributed across the three response keys.

Rensink et al. (2000) also found a different pattern of results when the change involved the orientation of an element (horizontal vs. vertical) than when the change involved the polarity of an element (black vs. white), concluding that the two types of change were handled in different ways. Given that the type of change to be detected in the present experiment (orientation) was quite different from the color change to be detected in Wright et al. (2010), it is possible that different cognitive processes are also at work in these two pigeon change detection tasks. Nevertheless, the central conclusion is that in both cases pigeons were able to successfully search for and identify changes in a stimulus display and that the presence of an ISI affected performance. Future research will hopefully provide additional detail about the cognitive processes underlying those successful performances.

As a follow-up to Experiment 1, these results support the interpretation that pigeons understood the procedure and selectively pecked changes, even on ISI trials, which featured multiple lines disappearing and reappearing at the onset and offset of the ISI. Accuracy on ISI trials in Experiment 1 was low, and although it was reliably better than chance, it was not far above it numerically. On the other hand, Experiment 2 demonstrated much better accuracy, even on trials that featured an ISI. In fact, accuracy on ISI trials rose to meet the high accuracy seen on no-ISI trials as the length of the ISI was shortened.

General Discussion

These two experiments establish a method for studying change blindness in pigeons that might possibly be modifiable

for use with other species. Furthermore, they identify some of the stimulus characteristics that reliably produce change blindness in pigeons and those are characteristics that similarly influence change blindness in humans. In particular, ISI duration and number of repetitions are both factors that affect the likelihood of successful change detection: shorter ISIs and more repetitions produced increases in change detection accuracy whereas longer ISIs and fewer repetitions decreased accuracy. Further investigation may reveal additional stimulus characteristics that affect performance in pigeons, and these may or may not parallel previous human results.

On a broader level, these experiments demonstrate that change blindness can be produced in at least two species using parallel methodologies. Although change blindness may carry some potential costs (e.g., failing to notice the appearance of a predator), it may be an inevitable consequence of the very nature of attention as an information processing bottleneck: not all incoming sensory information can be processed deeply; therefore, some must be filtered out at an early stage. Again, the adaptive aspect of attention is the ability to preferentially allocate cognitive resources to those input channels that are most likely to be important. Because the natural world is highly variable, the best manner of allocating attentional resources cannot always be determined, and important elements (including, but not limited to changes) may be missed. Therefore, we believe that the most interesting aspect of these results is not the mere existence of change blindness in a nonhuman animal, but that so far it appears to be influenced by some of the same variables as it is in humans (an animal suited to a much different ecological niche) and in roughly the same way.

Although the general pattern of results here is consistent with previous investigations of human change blindness, we must remain tentative regarding the underlying cognitive processes. First, note that pigeons produced lower overall accuracy than is seen in a typical human experiment, although there were fewer locations to search. This might be a product of the relatively few iterations available for search on a given trial (from 1 to a maximum of 16), or it might reflect a genuine difference in perceptual or attentional processes. Second, it is interesting that pigeons' performance on no-ISI trials increased with the number of repetitions, suggestive of an active, serial search process. Humans often report that changes "pop out" on no-ISI trials and do not require an active search, resulting in no increase in accuracy over time. This difference might be due to the different visual systems in pigeons and humans. Humans ordinarily are presented with a display that falls entirely within the available visual field; thus, a change would be potentially visible regardless of its location without need for a head movement. On the other hand, pigeons spent the display portion of a trial pecking individual response keys. It is thus likely that they could not see all three keys at one time and were thus forced to engage in a slower, serial search across the three keys, even on trials that did not feature an ISI.

The general conclusion we can draw from these two experiments is that change blindness is yet another phenomenon of attention that displays a striking parallel between pigeons and humans and thus strengthens the notion that animal models of attention can be valuable research tools. In this case, the comparative data have the potential to provide insight into not just what we can see and why, but also what we cannot see.

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