Detection of Object Onset and Offset in Naturalistic Scenes

Maria J. Donaldson and Naohide Yamamoto*

Department of Psychology, Cleveland State University
2121 Euclid Avenue, Cleveland, OH 44115, USA
{m.j.donaldson,n.yamamoto}@csuohio.edu
http://academic.csuohio.edu/n_yamamoto/lab/

Abstract. The present study was conducted to investigate whether observers are equally prone to overlook any kinds of visual events in change blindness. Capitalizing on the finding from visual search studies that abrupt appearance of an object effectively captures observers' attention, the onset of a new object and the offset of an existing object were contrasted regarding their detectability when they occurred in a naturalistic scene. In an experiment, participants viewed a series of photograph pairs in which layouts of seven or eight objects were depicted. One object either appeared in or disappeared from the layout, and participants tried to detect this change. Results showed that onsets were detected more quickly than offsets, while they were detected with equivalent accuracy. This suggests that the primacy of onset over offset is a robust phenomenon that likely makes onsets more resistant to change blindness under natural viewing conditions.

Keywords: Change blindness, change detection, scene, onset, offset

1 Introduction

Vision can provide rich information about details of an environment, if observers specifically attend to them. Conversely, when sufficient attention is absent, it is surprisingly easy to miss large changes in the visual field. For example, people often do not notice anything when an object in a movie scene suddenly appears or disappears from one clip to the next [1]. Typically, such failure in noticing changes occurs when they take place during a brief disruption of visual access to the environment (e.g., while blinking or during saccadic eye movements [2]) or when they are accompanied with other prominent visual events [3]. This inability to detect potentially salient changes is called change blindness, and it has been well demonstrated that observers can be unaware of a variety of changes such as displacement of an object [4] and color change in an existing object [5], to name but a few (for review, see [6, 7]). However, what remains unclear is

* This is a postprint of an article that has been published in Springer's *Lecture Notes in Computer Science* (August 2012, vol. 7463, pp. 451–460, doi: 10.1007/978-3-642-32732-2_29). The original publication is available at www.springerlink.com.

whether observers are equally prone to overlook any kinds of change or they are more resistant to change blindness with certain kinds of change. The purpose of the present study was to address this issue by focusing on two major types of visual change that happen in everyday environments: onset (appearance) and offset (disappearance) of an object. An experiment was conducted to investigate whether onset and offset in a naturalistic scene differ in their susceptibility to change blindness.

An important clue for approaching this question has been provided by studies on visual search. In these studies, observers were typically presented with an array of simple objects such as alphanumeric characters and geometric shapes, and then instructed to indicate the presence of a target among distractors. It has been found that how quickly and accurately the observers detect a target is strongly influenced by stimulus attributes the target possesses. For example, targets that display unique shape, color, or movement in the search array tend to be detected with greater speed and accuracy [8, 9]. Importantly, among these different types of targets, one of the most robust targets that consistently elicits enhanced detection is an object that abruptly appeared in the search array [10]. Although sudden disappearance of an object also makes an effective target [11], direct comparisons between appearing objects and disappearing objects often showed that targets defined by their appearance induce more efficient detection than those defined by their disappearance [12–14]. These results indicate that observers can notice the onset of a new object more easily than the offset of an existing object, suggesting that onsets are more resistant to change blindness than offsets.

However, great caution must be taken when findings from visual search studies are used to predict that onset should have higher resistance to change blindness than offset. This is due to the fact that previous studies on visual search and those on change blindness have utilized substantially different visual stimuli to carry out their investigation. In visual search studies, search arrays were constructed by arranging simple objects (e.g., letters) in a restricted manner so that various variables that could affect search efficiency (such as color, luminance, and locations of objects) were tightly controlled. As a result, the primacy of onset over offset was established under conditions in which there were few other visual features that could concurrently influence observers' performance. On the other hand, change blindness has typically been investigated by using photographs of real-world scenes that contained diverse visual features [4]. Thus, in order to make predictions regarding change blindness by applying the finding from visual search studies, it needs to be examined first whether the onset primacy is robust enough to be observed under viewing conditions in which many concomitant variables are less controlled.

Initial efforts have already been made to bridge the gap between visual search studies and change blindness studies. Cole and colleagues [13] presented colored pictures of an array of household objects and asked participants to detect a change that occurred in the array. The change was either the onset of a new object or the offset of an existing object. Consistent with their previous exper-

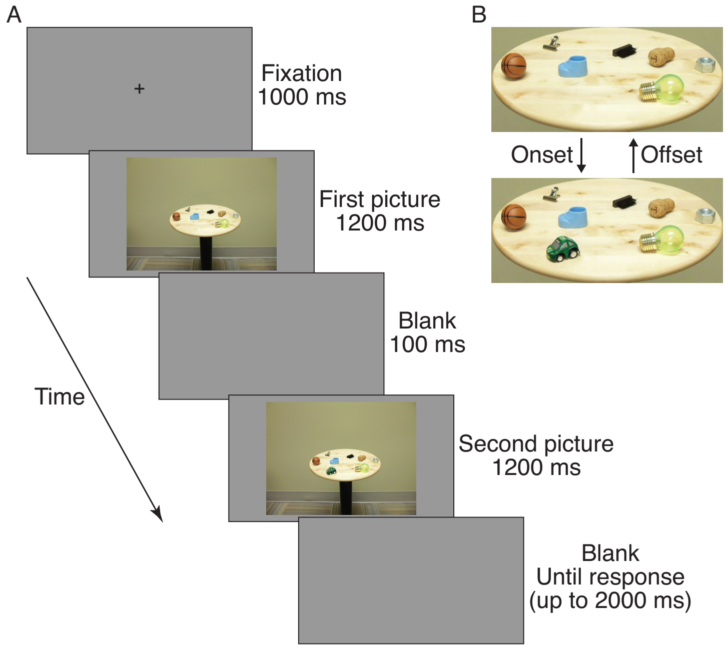

Fig. 1. (A) The trial sequence and examples of scene stimuli used in the present experiment. In this case, an object (the car) is added to the second image on the left-hand side. (B) Close-up views of the object array.

iments in which an array of simple geometric shapes was used, onsets were detected more accurately than offsets in this experiment. This provided important first evidence that the onset primacy holds true when the search array contains a wide variety of visual features. However, in order to make the array of household objects look sufficiently similar to search arrays used in other experiments, Cole et al. [13] arranged the objects in an arbitrary configuration and took the pictures from an aerial perspective. As a result, although the array of household objects successfully facilitated cross-experiment comparisons, it did not afford naturalistic viewing conditions that observers have in typical change blindness studies.

There were two studies that used photographs of real-world scenes to examine whether onsets and offsets are detected with different degrees of efficiency. In Mondy and Coltheart's study [15], an object was digitally added to or deleted from an existing photograph and participants tried to detect the onset or offset of the altered object. Mondy and Coltheart found that offsets were detected more accurately than onsets in this study. Brockmole and Henderson [16], on the other hand, took a different approach by making two new photographs of a scene with or without an additional object. These two photographs were presented successively and seamlessly while participants were viewing them, thereby creating an onset or offset of the object. Participants' eye movements were recorded during viewing, and it was found that they tended to fixate the area occupied by the changed object sooner when it appeared in the scene than when it disappeared from the scene. This result suggests that onsets were detected more quickly than offsets.

In summary, findings have been mixed when actual scenes were used to contrast onsets and offsets regarding their vulnerability to change blindness [15, 16]. This discrepancy cannot be resolved by experiments using complex real-world scenes because each of those scenes contains a unique set of visual features and semantic contexts. In other words, there is always a possibility that observed findings stemmed from some peculiar characteristics that happened to be possessed by particular scenes used in the experiments. Thus, in order to investigate whether the primacy of onset over offset is still observable under naturalistic viewing conditions, it is necessary to conduct an experiment that utilizes more controlled but still realistic scene stimuli. The present study was designed to carry out this investigation by developing simple three-dimensional scenes that afforded much more natural viewing conditions than the bird's-eye views of arbitrarily arranged objects [13] while maintaining good control over various visual features that might affect detectability of objects. If onsets were detected with greater speed or accuracy than offsets in the experiment reported below, it would increase the likelihood that onsets are more immune to change blindness than offsets even under naturalistic viewing conditions. On the other hand, if the experiment failed to find the advantage of onsets over offsets in change detection, it would support a claim that the onset primacy is a subtle phenomenon that can be observed reliably only under tightly controlled viewing conditions, and therefore the susceptibility of onsets and offsets to change blindness is mostly equivalent in everyday scene viewing.

2 Method

2.1 Participants

Thirteen participants (4 males and 9 females, 19–47 years of age) from the Cleveland State University community volunteered in return for extra credit in psychology courses. All participants were right-handed and reported normal or corrected-to-normal vision.

2.2 Materials

Experimental stimuli presented to participants were color digital pictures that depicted a wooden round tabletop on which six to nine objects were placed in various different arrangements. The objects were toys and small household goods that were approximately 4 cm in width, 2 cm in depth, and 3 cm in height. The tabletop was 38 cm in diameter and supported by a table base that was 75 cm tall. The objects were spread across the entire tabletop such that every object was visible in its entirety. The wall behind the table was also visible, as was the carpet on which the table stood. These additional items in the stimuli provided rich depth cues, thereby making the depicted scenes more naturalistic. For examples of the stimuli, see Fig. 1.

These images were presented on a 21.5-inch liquid crystal display by using the PsyScope program [17]. The screen was positioned vertically in front of the participant. The distance between the participant and the screen was approximately 60 cm. The images were presented in the center of the screen against a gray background and subtended approximately 29.3° (horizontal) × 22.3° (vertical) of visual angle. The tabletop measured 14.3° horizontally and 6.7° vertically. When presented on the screen, the center of the tabletop was approximately at the center of the screen.

2.3 Design

The experiment was modeled after the paradigm developed by Cole et al. [13]. Participants viewed a series of photograph pairs in one block. Each pair constituted either an onset trial in which a new object was added to the second image or an offset trial in which one of the objects in the first image was deleted in the second image (see Fig. 1). The same 64 photograph pairs, in which images contained either seven or eight objects, were used to create onset and offset trials by reversing the order of presentation of two images in each pair. The 128 trials (64 onset trials and 64 offset trials) composed of these pairs were the experimental trials from which data were collected. By using the same photograph pairs for these experimental trials, it was ensured that any particular properties of objects or their configurations (such as their color, location, or semantic salience) would equally affect onset and offset trials. In the experimental trials, each object was used the same number of times to create an onset trial or an offset trial (i.e., all objects were presented an equal number of times). The participant's task was to detect the change as accurately and quickly as possible by indicating whether it occurred in the right half or the left half of the tabletop. The location of the change was counterbalanced such that in half the onset trials objects in the left side changed and in the remaining half the objects in the right side changed. The same was done for offset trials.

Additional 32 pairs of photographs were used to create filler trials in which either an eight-object image was followed by a nine-object image or a seven-object image was followed by a six-object image. These filler trials (16 onset trials and 16 offset trials) were added to make the first image of each pair unpredictable of trial types: Without the filler trials, participants could potentially figure out whether it would be an onset trial or an offset trial just by looking at the first image (e.g., a seven-object image as the first image could indicate that an eight-object image would follow). Given that these numbers of objects (seven or eight) exceed the typical capacity of visual short-term memory (approximately four objects or six locations under optimal conditions [18, 19]), it is unlikely that participants were actually able to predict the trial type. Furthermore, it was not readily clear whether this predictability would differentially affect performance in onset and offset trials. However, the filler trials reduced any such biases if they existed. As a result of adding the filler trials, participants performed 80 onset trials and 80 offset trials in total that were randomly intermixed. Data from the filler trials were not included in the analysis.

After receiving instructions about how to perform the task, participants did 16 practice trials (eight onset trials and eight offset trials randomly intermixed). Photograph pairs that were not used in the experimental or filler trials were presented in these practice trials. Participants were not given any feedback on their performance throughout the experiment.

2.4 Procedure

Participants were told that they were going to view a series of photograph pairs in which an object would somehow change between two images of each pair; however, they were not informed of the nature of the change. They were instructed to press either the F key or the J key of a standard American English computer keyboard, depending on where on the tabletop the change occurred: The F key was for changes in the left and the J key was for changes in the right. They were also instructed to place their index fingers on these two keys all the time. They were cautioned to be as quick and accurate as possible. They were run individually.

Fig. 1A illustrates the trial sequence. In each trial, participants first viewed a fixation cross for 1000 ms that was presented at the center of the tabletop. They were instructed to keep fixating on the cross while it was displayed. However, eye movements were not constrained while participants viewed subsequent images. They then viewed the first image for 1200 ms, which was followed by a brief (100 ms) blank gray screen. The second image immediately followed and was displayed for 1200 ms. After the second image, the screen turned into gray until participants made a response or 2000 ms passed, whichever came faster. Subsequently, participants were presented with the fixation cross again, which indicated the beginning of the next trial. Reaction time was defined as time elapsed between the appearance of the second image and the participants' key press. Accuracy in the left/right judgment was also measured. When incorrect responses were made, reaction time data from those trials were excluded from the analysis. When no response was made, it was regarded as an incorrect response.

3 Results

Data from two participants were excluded from the analysis because their overall accuracy (8.6% and 63.1%) was substantially lower than that of the rest of the group (96.7%). Thus, data from 11 participants were analyzed below. Reaction time and accuracy were separately compared between two trial types (onset or offset) by paired t-tests.

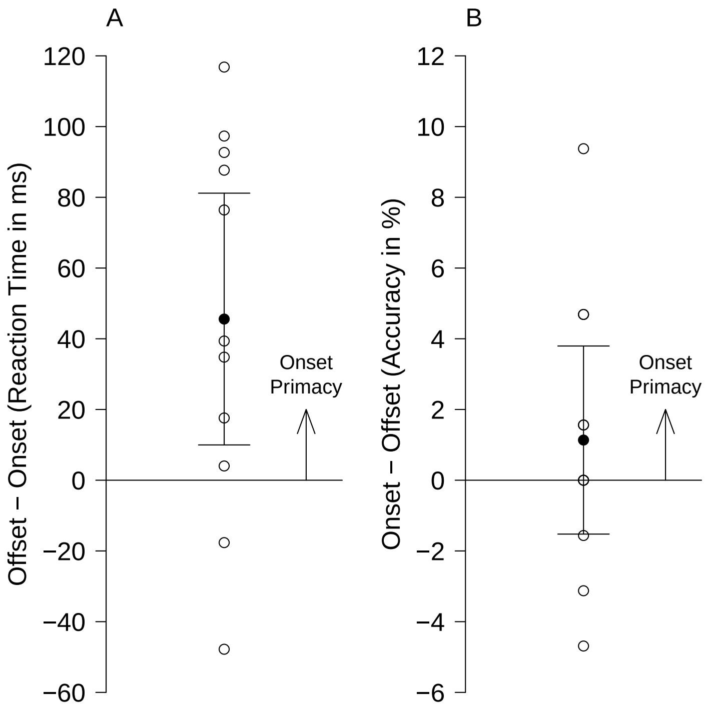

Fig. 2. Differences between onset and offset trials in (A) reaction time and (B) accuracy. Each open circle represents one participant. Filled circles represent the means of all participants. Error bars represent 95% confidence intervals. Note that the direction of subtraction between onset and offset trials is reversed in reaction time and accuracy so that positive values indicate onset primacy in both panels.

3.1 Reaction Time

After removing trials in which incorrect responses were made, mean reaction time was computed for each participant and for each trial type. Outliers were defined as data points that were more than three standard deviations away from each participant's mean reaction time to each trial type. Twenty-eight data points were defined as outliers and removed from the analysis. They constituted 2.0% of the data.

Fig. 2A plots differences between onset and offset trials (defined by offset − onset) shown by each participant. As illustrated in this figure, participants responded to onsets with significantly shorter reaction time, $t(10) = 2.85, p = .017$. Mean reaction time (M) and standard deviation (SD) for each trial type were as follows: $M = 668.3$ ms, $SD = 310.2$ ms (onset); $M = 713.9$ ms, $SD = 284.2$ ms (offset).

3.2 Accuracy

Fig. 2B plots differences between onset and offset trials (defined by onset − offset) shown by each participant. Although participants responded to onsets with higher accuracy than offsets, this difference was not statistically reliable, $t(10) = 0.95, p = .36$. Mean accuracy and standard deviation for each trial type were as follows: $M = 97.3\%, SD = 2.1\%$ (onset); $M = 96.2\%, SD = 3.4\%$ (offset).

Mean accuracy for each trial type was reliably different from 100%, $t(10) = -4.25, p = .0017$ (onset); $t(10) = -3.77, p = .0037$ (offset), confirming that there were no ceiling effects.

4 Discussion

The present study was conducted to investigate whether the onset of a new object is detected with greater speed or accuracy than the offset of an existing object when they occur in a naturalistic scene. Participants responded more quickly to onsets than to offsets, while they noticed both types of change equally accurately. These results suggest that the primacy of onset over offset regarding their detectability is robust enough to endure in a complex visual environment, thereby making onsets less susceptible to change blindness than offsets.

Why should the detection of onsets be more enhanced than that of offsets? One possibility is that onsets draw observers' attention more strongly than offsets. When a new object appears, it requires observers to newly form a mental representation of the object (so-called object file [20]). It has been proposed that the creation of an object file causes observers' attention to be directed to the new object in an exogenous manner [21]. When an object disappears, on the other hand, it only entails the deletion of an existing object file. It is likely that this process does not always result in the increase of attention to the disappearing object, making observers less efficient in detecting offsets.

Another possibility is that onsets are easier to detect than offsets because onsets are usually accompanied with a greater amount of sensory transients. When an object appears in a scene, it locally creates a large change in luminance (e.g., from plain gray to a complex combination of various patterns in the current experiment). On the other hand, when an object disappears, it tends to reveal only a background that is filled with a relatively simple pattern (e.g., from the gray to the wooden board pattern). Thus, it is possible that a larger amount of luminance change allowed observers to accumulate sufficient information sooner for determining the presence of an onset than an offset. The results from the present experiment are consistent with both possibilities, and in fact, there has been an active debate in the visual search literature as to whether it is a new object itself or the contribution of accompanying sensory transients that makes the detection of onsets especially efficient [22, 23]. It would be an important challenge for future research to examine (and resolve) this issue in the context of change blindness as well.

Given that many of the previous studies and the present study provided evidence for the primacy of onset over offset, it is not readily clear why Mondy and Coltheart [15] found that offsets were detected more accurately than onsets. One possibility is that some idiosyncratic characteristics of the stimuli used by Mondy and Coltheart caused their unique finding. For example, it is conceivable that digital alteration of the photographs produced sharper-than-usual contrasts between an altered object and its surroundings, and they somehow biased detection accuracy in favor of offsets. This possibility did not exist in the Brockmole and Henderson's study [16] and in the present study because two photographs were taken with or without an additional object to create onsets and offsets. Another point of note is that Mondy and Coltheart only measured accuracy. This leaves open the possibility that there were speed-accuracy tradeoffs in their study. That is, it is possible that offsets were indeed more difficult to detect in their experiments too, but the increased difficulty led participants to slow down in offset trials, resulting in higher accuracy for offsets than onsets. The present study excluded this possibility by measuring both reaction time and accuracy.

In conclusion, the present study showed that the onset of a new object can be detected more efficiently than the offset of an existing object, even when scenes are more realistic and thus contain more visual noises than abstract arrays of simple objects. This helps bridge the gap between visual search studies and change blindness studies, facilitating the use of rich knowledge gained through visual search studies for understanding change blindness. In particular, it is suggested that not all visual events are equal in their susceptibility to change blindness; rather, as results from visual search studies indicate, abrupt onset of a new object is especially resistant to change blindness. Future studies should build on this finding to investigate the mechanisms with which the detection of onsets is enhanced under naturalistic viewing conditions.

Acknowledgments. The authors thank Kamil Klinkosz for assistance with stimulus development and data collection.

References

1. Levin, D.T., Simons, D.J.: Failure to Detect Changes to Attended Objects in Motion Pictures. Psychon Bull Rev 4, 501–506 (1997)
2. Grimes, J.: On the Failure to Detect Changes in Scenes across Saccades. In: Akins, K. (ed.) Perception. Vancouver Studies in Cognitive Science, vol. 5, pp. 89–110. Oxford University Press, New York (1996)
3. O'Regan, J.K., Rensink, R.A., Clark, J.J.: Change-Blindness as a Result of 'Mudsplashes.' Nature 398, 34 (1999)
4. Rensink, R.A., O'Regan, J.K., Clark, J.J.: To See or Not to See: The Need for Attention to Perceive Changes in Scenes. Psychol Sci 8, 368–373 (1997)
5. Arrington, J.G., Levin, D.T., Varakin, D.A.: Color Onsets and Offsets, and Luminance Changes Can Cause Change Blindness. Perception 35, 1665–1678 (2006)
6. Rensink, R.A.: Change Detection. Annu Rev Psychol 53, 245–277 (2002)

7. Simons, D.J., Rensink, R.A.: Change Blindness: Past, Present, and Future. Trends Cogn Sci 9, 16–20 (2005)
8. Franconeri, S.L., Simons, D.J.: Moving and Looming Stimuli Capture Attention. Percept Psychophys 65, 999–1010 (2003)
9. Theeuwes, J.: Stimulus-Driven Capture and Attentional Set: Selective Search for Color and Visual Abrupt Onsets. J Exp Psychol Hum Percept Perform 20, 799–806 (1994)
10. Yantis, S., Jonides, J.: Abrupt Visual Onsets and Selective Attention: Evidence from Visual Search. J Exp Psychol Hum Percept Perform 10, 601–621 (1984)
11. Theeuwes, J.: Exogenous and Endogenous Control of Attention: The Effect of Visual Onsets and Offsets. Percept Psychophys 49, 83–90 (1991)
12. Cole, G.G., Kentridge, R.W., Heywood, C.A.: Visual Salience in the Change Detection Paradigm: The Special Role of Object Onset. J Exp Psychol Hum Percept Perform 30, 464–477 (2004)
13. Cole, G.G., Kentridge, R.W., Heywood, C.A.: Detectability of Onsets versus Offsets in the Change Detection Paradigm. J Vis 3, 22–31 (2003)
14. Cole, G.G., Kuhn, G.: Attentional Capture by Object Appearance and Disappearance. Q J Exp Psychol (Hove) 63, 147–159 (2010)
15. Mondy, S., Coltheart, V.: Detection and Identification of Change in Naturalistic Scenes. Vis Cogn 7, 281–296 (2000)
16. Brockmole, J.R., Henderson, J.M.: Object Appearance, Disappearance, and Attention Prioritization in Real-World Scenes. Psychon Bull Rev 12, 1061–1067 (2005)
17. Cohen, J., MacWhinney, B., Flatt, M., Provost, J.: PsyScope: An Interactive Graphic System for Designing and Controlling Experiments in the Psychology Laboratory Using Macintosh Computers. Behav Res Methods Instrum Comput 25, 257–271 (1993)
18. Jiang, Y., Olson, I.R., Chun, M.M.: Organization of Visual Short-Term Memory. J Exp Psychol Learn Mem Cogn 26, 683–702 (2000)
19. Luck, S.J., Vogel, E.K.: The Capacity of Visual Working Memory for Features and Conjunctions. Nature 390, 279–281 (1997)
20. Kahneman, D., Treisman, A., Gibbs, B.J.: The Reviewing of Object Files: Object-Specific Integration of Information. Cogn Psychol 24, 175–219 (1992)
21. Yantis, S.: Stimulus-Driven Attentional Capture. Curr Dir Psychol Sci 2, 156–161 (1993)
22. Davoli, C.C., Suszko, J.W., Abrams, R.A.: New Objects Can Capture Attention without a Unique Luminance Transient. Psychon Bull Rev 14, 338–343 (2007)
23. Hollingworth, A., Simons, D.J., Franconeri, S.L.: New Objects Do Not Capture Attention without a Sensory Transient. Atten Percept Psychophys 72, 1298–1310 (2010)