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Partial Representations of Scenes in Change Blindness: In the Eyes and in the Hands

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Abstract

Change blindness is a person's inability to notice changes in a visual scene that seem obvious when pointed out. Recent experiments using eye tracking techniques have suggested that even though participants do not detect a change they fixate on the changing area more. Two studies test whether this finding is present across different change blindness paradigms and whether it is detectable after fixation. In the first study we compare behavior in flicker and gradual change paradigms. Results reveal that across paradigms participants do spend more time on the changing area yet do not detect the change. In the second study we test whether we can capture the traces of change blindness in mouse movement. Findings indicate that accuracy has more of an impact on mouse movement than presence of change.

Keywords: change blindness, mouse movement, eye tracking, decision making.

Introduction

Change blindness occurs when a seemingly obvious occurrence within one's range of vision escapes attention. Many studies have investigated the notion of change blindness. These studies have shown that people fail to see changes in videos, photographs, and even in real life situations about 50% of the time, although these changes are obvious after they have been pointed out (Hollingworth, 2003; Levin, Simons, Angelone, & Chabris, 2002; Rensink, O'Regan, & Clark, 1997; Simons & Chabris, 1999; Simons & Levin, 1997). Evidence for change blindness has been found in both lab and in real life settings and can be induced in various ways (see Rensink, 2002 for an overview). Two of the more common ways to induce change blindness are flicker and gradual changes (Rensink et al., 1997; Simons, Franconeri, & Reimer, 2000). The flicker technique induces change blindness by rapidly presenting two images of the same scene each followed by a blank slide to act as a disruptor (Rensink et al., 1997). The gradual change technique induces change blindness by changing part of the visual scene gradually over a ~12 second viewing time (Simons et al., 2000).

David, Laloyaux, Devue, and Cleeremans (2006) compared flicker and gradual change techniques and found that participants were better able to detect changes in flicker videos than in gradual videos, suggesting these two techniques are different and might tap into different perceptual and cognitive processes.

Hollingworth, Williams, and Henderson (2001) suggested that change attracts attention. Using a flicker paradigm they found that participants fixated for longer duration on the changing aspect of a scene when they detected the change. More interestingly, they also found participants fixated more on the changing scene even when they did *not* detect the change.

Hollingworth et al. (2001) reported an important finding, because they suggest that change blindness might say more about cognitive processes than visual perceptual processes. Thus far, Hollingworth et al.'s finding is limited to flicker techniques and might therefore be an artifact of the technique rather than a conclusion for change blindness in general. However, Hollingworth et al.'s finding has not been investigated for the possibility that cognitive processes might explain the change blindness effect. In this paper, we showcase two studies intending to test whether partial detection of changes may take place even when detection may not occur. The first experiment shows that two commonly used change blindness techniques have similar effects, suggesting that it is not low-level perceptual features that are driving this sub-threshold processing. The second experiment tests whether this processing makes its way to post-viewing decisions, which would shed further light on how detailed these representations are. We first begin with a background summary of action dynamics measures to justify its use in this design.

Action Dynamics and Cognition

Cognition is not a rigid set of processes, but can be thought of as a continuous, dynamic system that is ever changing from moment to moment. Research in the area of action dynamics has shown that cognitive processes can be tracked at a continuous rate by looking at continuous motor actions such as arm movements (Dale, Roche, Snyder, & McCall, 2008). Rather than using static response measures, the action dynamics approach taps into the evolution of a cognitive process, as it approaches one or another option present in a task environment. Dale, Kehoe, and Spivey (2007) found that arm trajectories differ when competing categories are presented with images of animals. Asking participants to choose the correct category for *whale* when presented with *mammal* and *fish* causes a competition in cognition, which is then represented in a differing pattern of physical movement than when non-competing categories are present (*mammal* and *bird*). Contrasting information in decision-making may literally pull us into differing directions. McKinstry, Dale, and Spivey (2008) found that when participants are deciding on the truth values of statements there is a distinct index in arm movement reaction to the decision-making process. Participants show a greater curvature in movement when deciding on statements with a low truth value and less curvature on higher truth value statements. When decision-making takes more effort due to higher levels of ambiguity (e.g. low truth value statements) physical movements mirror the dissonance being experienced within the mind. The same is true for when there is little cognitive dissonance (i.e. less curvature in movements regarding high truth value statements).

Spivey, Grosjean, & Knoblich (2005) found that arm movement trajectories do not move directly to an intended item, but will curve towards a competitor option before selecting the correct item. Dale, Roche, Snyder, & McCall (2008) used an action dynamics approach to map out learning as it took place. By mapping the arm movements of participants, paired-associate learning expressed particular patterns and changes to those patterns as the learning progressed and deepened. Just as learning and lexical decision-making can be mapped out using this action dynamics approach, decision-making in other cognitive aspects can also be analyzed using this process. In change blindness, participants are asked if they perceive a change in the visual stimuli presented. However, previous studies of change blindness have not looked directly at the decision-making process that is taking place during this particular question.

The current study employs eye tracking in both flicker and gradual change paradigms to investigate Hollingworth and Henderson's (2002) findings at a perceptual level. In addition, we also investigate at a cognitive level by utilizing the motor movements involved in the decision-making process of change blindness. Using the action dynamics approach, the continuous process of decision-making can be tracked as they take place in real time. Indices present in subtle arm curvature may also reveal that participants have detected a subtle change just beneath the level of conscious perception.

Experiment 1

In order to expand on Hollingworth and Henderson's (2002) findings we performed an eye-tracking experiment where participants' eye gaze was monitored while they watched flicker and gradual change inducing videos. Following the viewing of each video, they were asked whether they saw a change and what the change was. We hypothesized that participants who noticed the change in flicker and gradual change videos would fixate on the changing areas more than participants who did not notice the change. More importantly, however, we hypothesized that even if participants did not notice a change, they would fixate on the changing area longer than participants in a non-changing baseline condition.

Participants

Thirty undergraduate students (17 female, 13 male) participated for Psychology course credit. All participants had normal or corrected-to-normal vision.

Stimuli

Materials included flicker and gradual video materials from Simons' (2003) *Surprising Studies of Visual Awareness* DVD, existing public domain images made available on the Internet by R. Rensink, and Robinson (2003). In order to increase the number of items, additional videos were created using a similar format and procedure as the Rensink et al. (1997) and Simons et al. (2000) videos.

In the study, 24 change videos were used each ~10 seconds long. The content of the various videos included scenes of ordinary things such as farms, office desks, beaches, and street scenes. One video, for instance, showed a scene with a wheat field in the foreground and a barn with a silo and trees in the background. In this video, the changing component consisted of the disappearance of a section of the wheat field.

The change videos were manipulated to obtain no-change control videos. To ensure that participants never saw the same video twice, the number of change videos displayed was lowered. These no-change control videos combined with filler videos, which never included a change, were included with the stimuli videos to obtain a 1:2 ratio of change/no-change stimuli so that participants were unlikely to strategically pick up on change patterns.

Apparatus

An SMI Hi-Speed eye tracker was used and had a 240 Hz sampling rate with a viewing angle of (horizontal/vertical) ± 30° / 30° (up), 45° (down). Participants' heads were stabilized by an adjustable ergonomic chin rest and forehead rest while they viewed the stimuli. All participants made responses using the keyboard. All stimuli were presented on an 800 x 600-pixel computer screen, and a 9-point calibration procedure was used for calibrating participants.

Design

The experiment was set up with a 2 (change or no-change) x 2 (flicker or gradual change) within subject factorial design. Participants saw 36 videos (12 change, 12 no-change, 12 filler), each ~10 seconds in length.

Participants were asked one question after each video they saw and their responses were recorded via yes/no response buttons on the keyboard. The question was ("did you notice a change in the video?") provided a basic measure of whether participants noticed a change.

Procedure

Participants were initially shown two examples of change videos: one flicker and one gradual change and were told that their task was to determine if there was a change in the video and to report their conclusion by pressing the appropriate response button. After the first eye gaze calibration, the experiment started. Participants viewed the videos and responded to the two questions. Calibration was monitored and corrected when needed throughout the experiment.

Results

Data for the filler videos were excluded from all analysis. Only fixation duration information was used for eye tracking analyses. For the fixation data outliers were identified as 2.5 standard deviations above the mean by subject by condition and were also removed from the analysis. This affected 3.4% percent of the data.

The areas of interests (AOIs) were identified as the changing area in the change videos, and the corresponding identical (but not changing) area in the no-change videos. Because not all of the videos were played for the same length of time and not all of the AOIs were the same size, data was normalized for time on task and space in pixels. This allowed for the comparison of both flicker and gradual change techniques. Total fixation time was divided by the total duration time of the video played, and this normalized fixation time was divided by the pixel area. The same algorithm was used to normalize regressions for time on task and space in pixels:

$$\text{Normalized fixation} = \frac{Fixation\ Time\ /\ Total\ time\ on\ task}{Norm.\ pixel\ area * Mean\ perc.\ of\ pixels\ on\ screen * Mean\ length\ of\ the\ video}$$

For all analyses reported here we used a mixed effects model for analysis of the data. In mixed effect models both participants and items are treated as random effects.

We checked for an order effect by initially putting participants into two groups. A mixed-effects model analysis was conducted on the total fixation time between the two groups. No differences between the groups were found. Therefore the data of the two groups were collapsed into one.

One concern in answering the question whether participants looked at an AOI without detecting the change was that participants used a strategy, for instance by looking at one specific area for the duration of the video and detecting changes. Even though we discouraged strategies by using a large proportion of filler videos, we verified that participants did not have a bias towards detecting a change by looking at proportions of signal detection ‘hit’ and ‘false alarm’ rates. The calculated *d’* = 1.575 and *C* = .692 showed that participants were sensitive to changes in the videos, and a bias towards saying there was not a change. This allowed for an ideal data set to examine whether participants were looking at the changing AOI even though they did not detect a change.

Response Data

Response accuracy for the question regarding whether or not there was a change showed that participants performed at about chance (50%). More specifically, participants detected a change in the flicker stimuli (*M* = .48) more often than in the gradual change stimuli (*M* = .21) *F*(1, 22) = 15.9, *p* < .001, *d* = .57. This difference between paradigms was similar to what David et al. (2006) found in their study using a somewhat different procedure.

Eye gaze

Previous eye tracking studies have shown that a changing area attracts more attention in general (Hollingworth & Henderson, 2002; Hollingworth et al., 2001) even when not detected. To test the aforementioned hypotheses we analyzed only the fixation times for those cases where a) participants reported no change and the video indeed did not display a change, and b) participants reported no change but the video did display a change, and ignored those cases of no-change videos where participants did (incorrectly) notice a change. We found that under the flicker condition, fixation times were longer on changing areas than non-changing areas, (Changing *M* = 7,000ms vs. Not Changing *M* = 5,073ms) *F*(1, 369.1) = 7.1, *p* < .01. However, for the gradual change condition there was not a significant difference when there was no detection between changing area and no-changing area, (Changing *M* = 3,897ms vs. Not Changing *M* = 3,624ms) *F*(1, 214.6) = .1, *p* = .74. This suggests that flicker conditions attract attention more readily than videos in the gradual condition. This is most likely due to gradual change videos presenting only one instance of a change per video to a participant.

A main effect was also found for change and no-change, showing that fixations on the area of interest in the change condition were significantly longer (*M* = 3,702ms, *SD* = 3,323ms) than those in the no-change condition (*M* = 2,837ms, *SD* = 2,685ms), *F*(1, 837.3) = 3.8, *p* = .05, *d* = .29. This finding is similar to what Hollingworth et al. (2001) found for flicker videos, confirming that a change in the video does attract attention even if people are not aware of the change. This finding could however be attributed to the flicker paradigm. Such an interpretation was not warranted by our data though, because no interaction was found between flicker and gradual change on the one hand and change and no change on the other *F*(1, 821.5) = 1.7, *p* = .19.

Discussion

Many change blindness studies have investigated the various conditions under which participants detect the changes in scenes, either in flicker or gradual change paradigms. Fewer studies have used eye tracking techniques to investigate what people fixate on during the change blindness task. One study in particular (Hollingworth et al.,

2001) has found that people can fixate on a changing object and not detect the change, but only in the flicker paradigm. The current study has gone a step further by considering whether this finding is unique to the perceptual characteristics of the flicker paradigm by including gradual change. The results suggest that gradual changes are more difficult to detect, but overall the results are identical. Even when participants do not detect a change, they do fixate on the changing area significantly more than a no-change baseline. This suggests that change blindness is not simply a visual perception phenomenon. If it were then we might expect to see more substantial differences in eye behavior. However, this could mean that change blindness is partially a cognitive phenomenon. Even if participants have physically seen the change, they are not cognitively aware that they have seen the change. The follow up study looks at whether the cognitive phenomenon aspects can be captured using an action dynamic approach.

Experiment 2

We wondered whether the decision-making process regarding change detection could still carry information about fixation in the cognitive system. If so, it may show up in action dynamics measures described in the introduction. We then conducted a similar experiment, but prompted participants to respond to a change using the computer mouse. For the second experiment we were interested in capturing the decision making process in change detection. To do this we looked at distance and deviation of mouse movements when responding. Based on findings from experiment one, we would predict that videos with no change should have less variability in curvature than videos with change because they should attract less attention. In addition, if participants spent more time looking at the target they should have less variability in their curvature, because there are more opportunities to make representational comparisons. Gradual videos were not used in this experiment based on the findings mentioned in the first experiment.

Participants

Twenty-six undergraduate students (20 female, 6 male) participated for Psychology course credit. All participants had normal or corrected-to-normal vision.

Stimuli

The same flicker videos from Experiment 1 were used in Experiment 2 with some additional videos added to fill in the gap left by removing the gradual videos and to increase item count. A total of 28 flicker videos with a change were used.

Apparatus

The same eye tracker, calibration settings, and computer screen presentation from Experiment 1 were used in Experiment 2.

Design

The experiment was set up with a 2 (change or no-change) within subject factorial design. Participants saw 56 videos, each ~10 seconds in length.

Immediately after the video, participants clicked on a button at the bottom center of the screen. This caused the question “did you notice a change in the video?” to appear at the bottom of the screen, and the available responses yes/no to appear at the top right and left, respectively. Mouse-movement trajectories of response were recorded (Spivey et al., 2005).

Procedure

Participants were initially shown an example change video, and were told that their task was to determine if there was a change in the video and to report their conclusion by clicking the corresponding response. After the first eye gaze calibration, the experiment started. Calibration was monitored and corrected when needed throughout the experiment.

Results

The distances and deviation of the mouse trajectories were calculated using MATLAB. The distance is defined as the length the mouse travelled in pixels from the starting x, y coordinates to the ending coordinates. Maximum deviation is the maximum distance from the trajectory to an assumed straight line. We first wanted to compare signal detection with Experiment 1. The biggest difference in Experiment 2 is that the proportion of False Alarms is much higher. The calculated d' = 0.823 and C = .305 showed that participants were less sensitive to changes in the videos, and less bias towards saying there was not a change. This could be due to the videos that were added were more difficult or some bias in responses.

Eye Gaze

We first carried out a series of exploratory analyses to see if eye-movement patterns predict mouse-cursor trajectories. Specifically, we hypothesized that longer overall fixation times on change area would result in shorter distances and less deviation in arm trajectories. A linear mixed effects regression was run with distance as the outcome variable, fixation duration as the predictor variable and subject as a random factor. Surprisingly, fixation had a non-significant effect on distance, $F(1, 488) = 0.002$, $p = 0.96$. We then ran the same analysis with deviation as the outcome variable. Again, fixation had a non-significant effect on deviation, $F(1, 488) = 0.01$, $p = 0.98$. Digging deeper we then ran a mixed effects regression including only trials that contained a change. Distance was the outcome variable, fixation duration as the predictor variable, and subject as a random factor. No significant effect was found, $F(1, 120) = 2.20$, $p = 0.14$. The same model was run with only trials in which no change occurred and a non-significant effect was found, $F(1, 366) = 0.51$, $p = 0.47$. We repeated these models, substituting deviation with distance and similar non-significant effects were found for change $F(1, 366) = 0.28$, $p = 0.59$, and for no change trials $F(1, 120) = 0.81$, $p = 0.37$. Taking all of these results into account would suggest that mouse movement is not influenced by fixation duration. We did not find a connection between eye gaze and mouse movements for change blindness.

Mouse Movement

Change / no change: In our primary set of analyses, we tested if there were any general effects from the presence or absence of a change on both mouse measurements. A mixed-effects regression was run with distance as the outcome variable, the presence of a change as the predictor variable and subject as a random factor. We found that the presence or absence of a change had no significant effect on the distance of the subjects' mouse movements, $F(1, 1{,}850) = 0.89$, $p = 0.35$. The same analysis was then run with deviation as the outcome variable with similar non-significant results, $F(1, 1{,}850) = 0.68$, $p = 0.41$. This is in contrast to the eye tracking results from the first experiment. In short, presence/absence of change by itself does not seem to induce differences in mouse trajectories.

Accurate / inaccurate: Furthermore we wanted to examine whether traces of participants' general decision making processes might be captured in the mouse movement. Participant accuracy was calculated for responding correctly and incorrectly on all videos. Accuracy was then used as a predictor variable for deviation/distance. The results indicate that accuracy was not a significant predictor of either distance, $F(1, 1{,}850) = 1.57$, $p = 0.46$, or deviation, $F(1, 1{,}850) = 0.53$, $p = 0.21$. This finding suggests that whether participants were correct or incorrect in their responses did not by itself influence their mouse movement. This might be because participants had already come to a decision of whether a change occurred before moving the mouse.

Just change trials: We then checked to see if there was anything going on in the trials where a change occurred similar to analysis in the first experiment. We ran a mixed effects regression which only included trials in which a change occurred using distance as the outcome variable, accuracy as the predictor variable and subject as a random factor. We found that distance increased significantly when participants answered correctly, $F(1, 934) = 7.75$, $p = 0.006$. Another regression was run with only trials that contained no change and results showed a decrease in distance when answering correctly, $F(1, 914) = 16.02$, $p < 0.001$. Similar results were found when deviation was substituted as the outcome variable with the presence of a change resulting in shorter deviations, $F(1, 934) = 7.05$, $p < 0.001$, and no change resulting in larger deviations, $F(1, 914) = 21.37$, $p = 0.008$. These results are the opposite of what we predicted earlier. To determine why this might be, we looked at interactions between video and response.

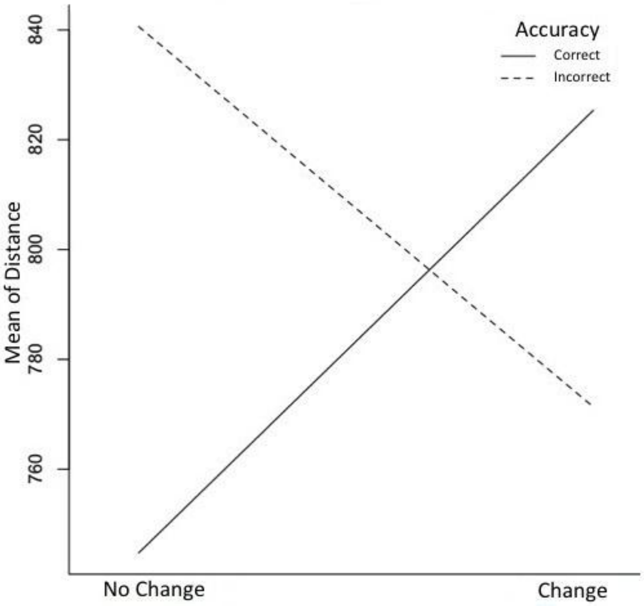

Figure 1: Interaction between participants' Accuracy and the presence of a change for Mean Distance.

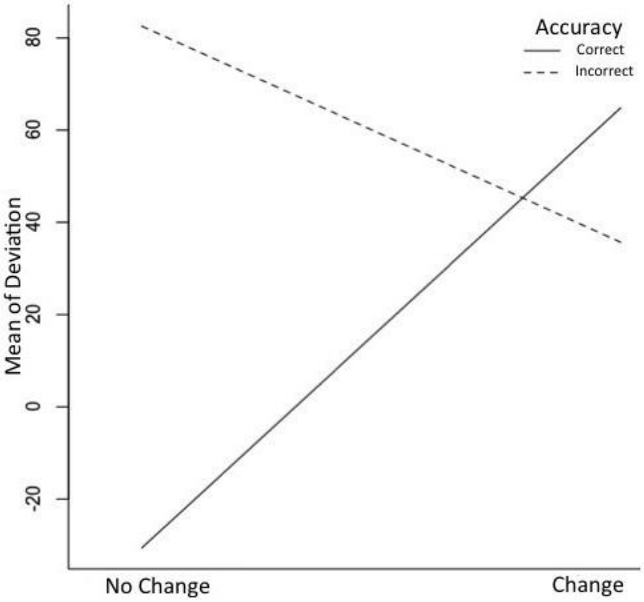

Figure 2: Interaction between participants' Accuracy and the presence of a change for Mean Deviation.

Interaction between change and accuracy: To test a possible interaction with accuracy and presence of change, both terms were centered and a mixed effects regression was run with distance as the outcome variable. Results showed a significant interaction between change and accuracy, $F(1, 1{,}848) = 25.14$, $p < 0.0001$ (See Figure 1). Deviation was then used as the outcome variable and a significant interaction was again found, $F(1, 1{,}848) = 27.34$, $p < 0.001$ (See Figure 2). Both results were plotted to see the graphical interaction between accuracy and change presence (See Figure 1 and Figure 2). In both plots, participants exhibited less confidence in their mouse movement when correctly answering there was a change, as if they were still debating if they noticed a change. Whereas when they correctly respond there was no-change they are more confident in their mouse movement, as if they have already decided there was no change before being asked.

General Discussion

In the first experiment we compared different types of change blindness videos to determine whether perceptual processes could clarify where change blindness occurs. We noted similar behavior in both types of videos suggesting that change blindness cannot be completely explained by perceptual processes. In the second experiment we used an action dynamic approach in order to capture the cognitive processes involved in deciding whether a change occurred or not. We found that confidence in decision making was only impacted when both the presence of a change and accuracy of response were taken into account.

These findings taken together imply that the cognitive processes involved in change blindness detection are most likely occurring before or as responses are given, but after the perceptual process of scene searching. This would suggest that there are two stages to change blindness. The first stage is during low level visual processing, such as at the fixation level. Obviously it is necessary for the change area to be fixated on. The second stage is during higher levels while processing the visual scene. At this stage, even though the change has been fixated on, it still needs further processing to be detected. In the current study, mouse movement served as an indirect way of measuring this higher level processing that is hypothesized to lead to detection. However, the measures employed in the current study are not fine grained enough to determine specifically when detection takes place.

We recommend that future research focus on the integration of perceptual and cognitive processes, such as metacognition (Smilek, Eastwood, Reynolds, & Kingstone, 2008) in order to better understand why what people see and what they detect is not always what they get.

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