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Does Unattended Information Facilitate Change Detection?

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Changes between alternating visual displays are difficult to detect when the successive presentations of the displays are separated by a brief temporal interval. To assess whether unattended changes attract attention, observers searched for the location of a change involving either a large or a small number of features, in pairs of displays consisting of 4, 7, 10, 13, or 16 letters (Experiment 1) or digits (Experiments 2 and 3). Each display in a pair of displays was presented for 200 ms, and either a blank screen (Experiments 1 and 2) or a screen of equal luminance to the letters and digits (Experiment 3) was presented for 80 ms between the alternating displays. In all experiments, the search function for locating the larger change was shallower than the search function for locating the smaller change. These results indicate that unattended changes play a functional role in guiding focal attention.

People often exhibit a striking failure to detect changes between two different views of an object or scene. Such failures to detect change have been found (a) when the presentations of a picture of a scene and an altered picture of the same scene are separated by a short temporal interval (e.g., Rensink, O'Regan, & Clark, 1997), (b) when an altered picture of an object is substituted for the original picture of the object during an eye saccade (e.g., McConkie & Currie, 1996), and (c) when an object or actor changes from one view of a scene to the next view of the same scene in a motion picture (Levin & Simons, 1997; Simons & Levin, 1997). These failures to detect change reflect what has been termed *change blindness* (cf. Rensink et al., 1997; Simons & Levin, 1997; Simons, in press), which is demonstrated whenever observers either fail to detect or have difficulty detecting changes between two successive views of an object or scene.

The experiments reported by Rensink et al. (1997) provide one example of change blindness. In their experiments, pictures of scenes and altered pictures of the same scenes were presented to observers who were asked to identify what was different between the two views of each scene. For some scenes, an object appeared in one view and disappeared in the other view, whereas for other scenes, objects changed color or location between the two views of the scene. Each view of each scene was presented for 240 ms, and the two views of each scene were continuously alternated until the observers detected the discrepancy between the two views of the scene. When the two views of a scene were simply alternated with no temporal interval between successive presentations, the observers had relatively little difficulty detecting the discrepancy between the two views. However, when the presentations of each view were separated by the presentation of a blank screen for 80 ms, the observers found it difficult to detect discrepancies between the two views. This difficulty in detecting discrepancies between successive views of scenes, or in other words, change blindness, is surprising because the general impression most people have when viewing a picture is that they are aware of most if not all of the details in the picture. Given this general impression, observers often believe that any changes between two successive views of a picture should be relatively easy to detect (Levin, Momen, Drivdahl, & Simons, in press).

Why is it then that observers find it difficult to detect a change between two views of a scene when the views are separated by a short temporal interval? According to Rensink and his colleagues (O'Regan, Rensink, & Clark, 1999; Rensink, in press; Rensink et al., 1997), change detection is relatively easy when there is no temporal interval between two views of a scene because any discrepancy between the two views entails an abrupt visual onset, which attracts attention to the location of the change (cf. Klein, Kingstone, & Pontefract, 1992; Yantis & Jonides, 1984). In contrast, change detection is more difficult when there is a short temporal interval (e.g., 80 ms) between the two views of a scene because there is no unique abrupt visual onset to attract attention to the location of the change. Rather, whenever the successive presentations of the two views of a scene are separated by a short temporal interval, there are many abrupt visual onsets each time a view of the scene is presented. Given that there is no unique abrupt visual onset to guide attention quickly to the location of a change under such conditions, Rensink and his colleagues have suggested

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that attention is guided solely by a much slower, controlled, serial search process.

An important implication of the interpretation of change detection proposed by Rensink and his colleagues (O'Regan et al., 1999; Rensink, in press; Rensink et al., 1997) is that unattended information regarding any change between displays has no functional role in guiding attention to the location of the change when the successive presentations of the displays are separated by a short temporal interval. Although the available evidence is certainly consistent with this proposal, the available evidence is also consistent with the alternative view that an unattended change between two successive displays does attract attention. At the empirical level, the available evidence simply indicates that change detection is more difficult when the successive presentations of displays are separated by a short temporal interval than when there is no temporal interval between the successive presentations. However, the findings do not necessarily show that unattended changes do not play a functional role in change detection when there is a temporal interval between successive presentations. Rather, the findings may simply show that a temporal interval between the successive presentations of the displays reduces the functional role of unattended changes in guiding the focus of attention to the location of the change. Given the available evidence, it is entirely possible that unattended information accumulates in memory across displays and plays a functional role in guiding attention to the location of the discrepancy or change between the displays.

Possible support for the idea that unattended information from successive presentations of a display accumulates in memory comes from a recent series of studies demonstrating that the presence of a change can be detected even when there is no awareness of the specific change (Fernandez-Duque & Thornton, in press). In these studies, sensitivity to the presence of a change was assessed by a two-alternative forced-choice discrimination task that required observers to choose between two possible locations of a change in displays consisting of either 8 or 16 items. It was found that the observers were able to choose the correct location of a change even when they reported that they did not see a change. These findings suggest that sufficient information to choose between two possible locations of a change is perceived and remembered even when there is no reported awareness of the change. However, the results do not indicate whether unattended information plays a functional role in guiding attention. It is entirely possible that even though unattended information may on occasion be both perceived and remembered without awareness, such information may not play any functional role in guiding the focus of attention to the location of the change.

The present experiments were designed to determine whether unattended changes play a functional role in change detection when a short temporal interval separates the successive presentations of each display. In the experiments, observers were asked to detect the location of a change in displays that consisted of either letters (Experiment 1) or digits (Experiments 2 and 3). Examples of the displays used in each experiment are shown in Figures 1 and 2. As illustrated in the figures, the *A* and *A'* displays in each experiment differed in terms of only a single item. For the displays shown in Figure 1, both the *A* and the *A'* displays consist of the letters *E*, *F*, and *L*. The only difference between the displays is that for the displays on the left side of the figure, an *E* in the *A* display changes to an *L* in the *A'* display, whereas for the displays on the right side of the figure, an *F* in the *A* display changes to an *L* in the *A'* display. Similarly, for the displays shown in Figure 2, both the *A* and the *A'* displays consist of the digits 2, 4, and 8, and the only difference between the *A* and the *A'* displays is that either an 8 or a 4 in the *A* displays changes to a 2 in the *A'* displays.

To assess the possible role of unattended changes in directing the focus of attention to the location of a change, two characteristics of the displays were varied. First, the discrepancy between the *A* and *A'* displays involved either a large or a small change. For example, consider the displays shown in Figure 1. For the change illustrated on the left side of the figure, observers were required to detect a change between the letters *E* and *L*, which involved a difference of two features—the addition or deletion of two horizontal lines. In contrast, for the change illustrated on the right side of the figure, the observers were required to detect a change between the letters *F* and *L*, which involved a difference of three features—the addition or deletion of three horizontal lines. Similarly, for the displays shown in Figure 2, the change between the digits 8 and 2 involves two features—the addition or deletion of two vertical lines, whereas the change between the digits 4 and 2 involves five features—the addition or deletion of three vertical lines and two horizontal lines. The basic assumption underlying this variation in the number of features defining the change or discrepancy between the displays was that the unattended changes involving a greater number of discrepant features should attract attention better than the unattended changes involving fewer discrepant features. This assumption is reasonable given recent findings showing that large changes are easier to detect than small changes (Williams & Simons, in press).

The second characteristic of the displays that was varied in the experiments was set size. Each pair of alternating displays consisted of either 4, 7, 10, 13, or 16 letters (Experiment 1) or 4, 7, 10, 13, or 16 digits (Experiment 2 and 3). By varying set size, it was possible to apply the logic of visual search experiments to determine whether any differences in change detection between the pairs of displays with large and small discrepancies were more consistent with the idea that change detection is guided solely by a controlled, serial search process, or more consistent with the idea that unattended changes play a functional role in directing attention to the location of the change between the displays.

A critical assumption underlying visual search experiments is that whenever the distractor context and the expectations of the observer are comparable across conditions, the differences in the slopes of the search functions reflect the relative role of preattentive processes in guiding focused attention to a target embedded within distractors (cf. Wolfe, 1994). Specifically, the more shallow the slope, the

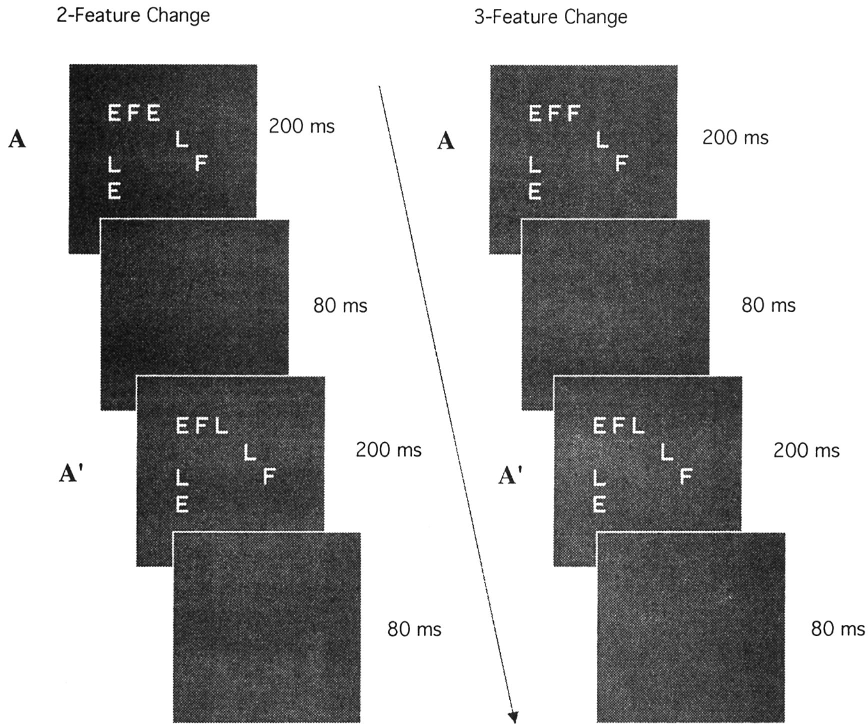

Figure 1. Examples of the stimulus displays used in Experiment 1.

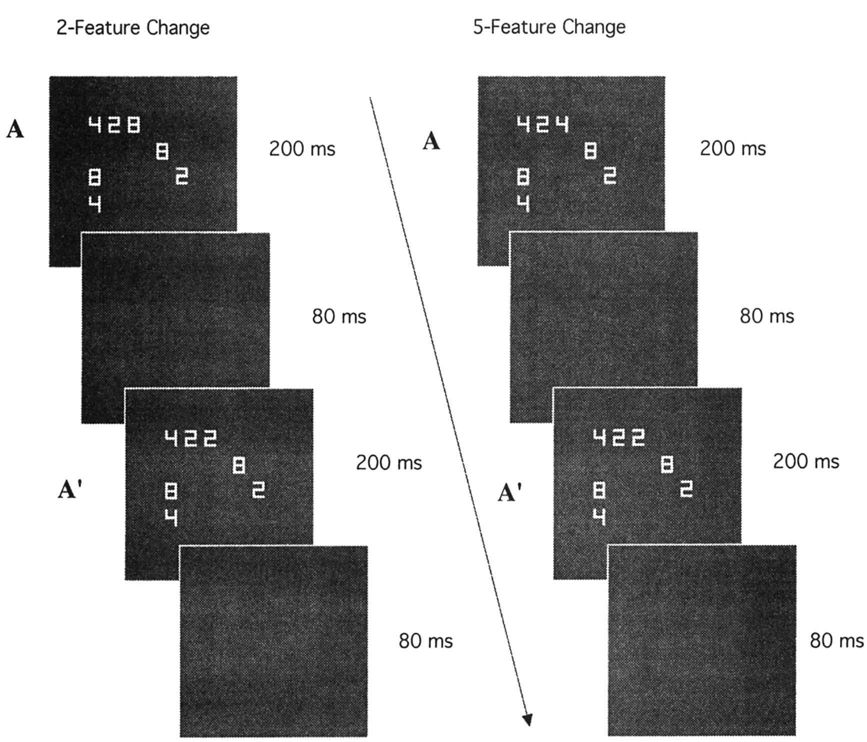

Figure 2. Examples of the stimulus displays used in Experiment 2.

greater is the relative role of preattentive processes in directing attention. Our application of visual search logic differs from prior experiments involving static displays, because in our experiments, neither the *A* nor *A′* displays contained a target. Thus, within each display, the item in the location of the change could not attract attention because it was not unique relative to other items in the display. The only unique characteristic of the item in the location of the change was that it was different in the *A* and *A′* displays (e.g., *F* or *L*), whereas the items in the other locations were the same in both displays. Critically, therefore, an item in the location of a change could only attract focused attention if there was memory for the unattended item in an *A* display at the time an *A′* display was presented or vice versa.

Given the assumption regarding the relation between the slope of a search function and the relative roles of preattentive and controlled, attentional processes in guiding search, a comparison of the search functions for small and large changes should reveal whether unattended changes play a functional role in directing attention to the location of the change between each pair of *A* and *A′* displays. If change detection is mediated solely by a controlled, serial search process, then the slopes of the search functions for detecting a large as opposed to a small change should be similar, and any difference between detecting large and small changes should only be reflected in the intercepts of the search functions. However, if unattended changes play a functional role in change detection, then the slopes of the search function for detecting the smaller changes should be steeper than the slopes of the search functions for detecting the larger changes. Thus, by comparing the slopes of the search functions for detecting the large and small changes, it is possible to determine whether unattended changes contribute to the guidance of focal attention to the location of the change.

Experiment 1

The purpose of Experiment 1 was to evaluate whether unattended changes play a functional role in guiding attention to the location of a change between two alternating displays. Each pair of *A* and *A′* displays used in Experiment 1 consisted of the letters *E*, *F*, and *L*. For the two-feature change, an *E* in the *A* displays changed to an *L* in the *A′* displays, whereas for the three-feature change, an *F* in the *A* displays changed to an *L* in the *A′* displays. For both types of change, the set size in each pair of *A* and *A′* displays was 4, 7, 10, 13, or 16 letters. If unattended changes attract attention, then the slope of the search function for detecting the two-feature change should be greater than the slope of the search function for detecting the three-feature change. Alternatively, if unattended changes do not play a role in guiding attention, then the slopes of the search functions should be similar.

Method

Participants. Eight undergraduate students at the University of Waterloo participated in the experiment. Each student had normal or corrected-to-normal vision and was paid $6.00 on completion of the 30-min experimental session.

Stimulus displays. Examples of the stimulus displays are shown in Figure 1. All displays were based on an imaginary 6 × 6 square matrix. For each pair of *A* and *A′* displays, the location of the critical letters (*E* and *L* or *F* and *L*) and the locations of the distractor letters (*E*, *F*, and *L*) were selected randomly. For the pair of critical letters, one letter (e.g., *E*) appeared in an *A* display, and the other letter (e.g., *L*) appeared in the same location in an *A′* display. For the distractor letters, the same letters appeared in the same locations in the *A* and the *A′* displays. In addition, the distractors in each pair of displays always consisted of equal numbers of each possible letter. For example, for a set size of 4, the *A* and *A′* displays consisted of 1 pair of critical letters (e.g., *E* and *L*) and 3 distractor letters consisting of one *E*, one *F*, and one *L*, whereas for a set size of 16, the *A* and *A′* displays consisted of 1 pair of critical letters and 15 distractor letters consisting of five *E*s, five *F*s, and five *L*s.

The two types of change (2 vs. 3 features) and the five set sizes (4, 7, 10, 13, and 16 letters) were manipulated within subjects. On each trial of the experiment, one of the 10 experimental conditions was selected, and an appropriate pair of *A* and *A′* displays was constructed for presentation. The experimental condition for each trial was selected randomly with the constraint that each of the 10 experimental conditions was selected and tested 30 times across a sequence of 300 experimental trials.

All stimulus displays were presented on a ViewSonic 17PS monitor that was driven by a 200 MHz Pentium processor running the Micro Experimental Laboratory software (Schneider, 1990). The imaginary 6 × 6 matrix measured 106 mm vertically and horizontally, and at the viewing distance of 60 cm, the matrix subtended a visual angle of approximately 10.1° in both the vertical and horizontal directions. Each letter in each display was light gray on a dark background and was centered in one of the squares defined by the matrix. The letters were approximately 13 mm high × 10 mm wide and subtended a visual angle of approximately 1.2° vertical × 1.0° horizontal.

Procedure. Each participant was tested in a single experimental session consisting of 10 practice trials and 300 experimental trials. At the beginning of each trial, a prompt was presented on the monitor screen instructing the participants to press the *b* key on the keyboard to initiate the trial. The participants were instructed to keep either their left or right index finger on the *b* key throughout each trial, and they were asked to respond as fast as possible on each trial while at the same time maintaining high accuracy. On each trial, the *A* and *A′* displays were presented in a continuous, alternating sequence until a participant pressed the *b* key to end the trial. The *A* and *A′* displays were each presented for 200 ms, and there was an 80-ms blank interval separating the offsets and onsets of successive displays.

At the end of each trial, the most recent display (i.e., either *A* or *A′*) remained on the monitor screen. Column and row numbers (i.e., 1 to 6) were then presented above and to the left of the display, respectively. The participants were asked to use the keyboard to enter the column and row numbers corresponding to the location of the item that changed. Each entry was displayed at the bottom of the monitor screen, and feedback concerning the accuracy of each entry (i.e., "accurate" or "error") was presented following a 500-ms blank interval. The prompt for the next trial was presented on the same screen as the feedback.

Results and Discussion

Reaction time (RT). Before the RTs for the correct responses were analyzed, the outliers in each cell were removed by applying a recursive procedure. Initially, the highest and lowest RTs were removed and the mean and standard deviation were calculated. If the temporarily removed RTs were more than 4 *SD*s from the mean, they were removed permanently. This procedure was then repeated until all deviant RTs in each cell were removed. A total of 2.39% of the RTs were removed in this manner before the data were submitted to a two-factor analysis of variance (ANOVA) that assessed type of change (2 vs. 3 features) and set size (4, 7, 10, 13, and 16).

Figure 3 shows the mean RT for each condition. Inspection of Figure 3 reveals that it was generally easier to detect the three-feature change than to detect the two-feature change, $F(1, 7) = 12.70$, $MSE = 73{,}381$, $p < 0.01$. This finding is consistent with previous findings showing that large changes are easier to detect than small changes (Williams & Simons, in press). Figure 3 also shows that search became more difficult with increased set size, $F(4, 28) = 26.55$, $MSE = 116{,}979$, $p < 0.01$, and that the slope of the search function for detecting the three-feature change (slope = 73.4) was considerably shallower than the slope of the search function for detecting the two-feature change (slope = 112.0), $F(4, 28) = 4.01$, $MSE = 45{,}319$, $p < 0.01$. This difference between the slopes of the search functions is not consistent with the suggestion made by Rensink and his colleagues (O'Regan et al., 1999; Rensink, in press; Rensink et al., 1997) that attention is guided solely by a controlled, serial search process. If attention had been guided solely by a controlled, serial search process, then the slopes of the search functions for locating two-feature and three-feature changes should have been similar. On the other hand, the observed difference between the slopes of the search functions is consistent with the idea that unattended changes play a functional role in guiding attention to the location of a change. This idea predicts that the slope of the search function for locating the three-feature change should be shallower than the slope of the search function for locating the two-feature change, which is exactly the pattern of results found in the experiment.

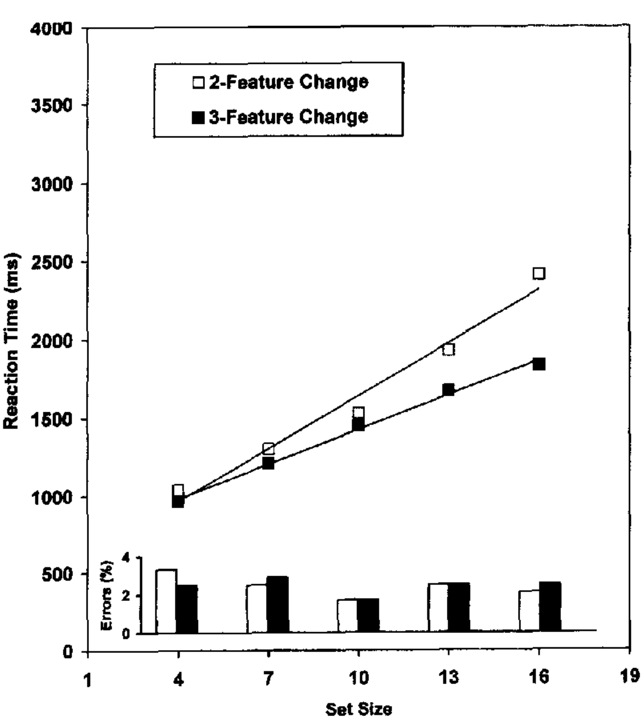

Figure 3. Mean reaction times and errors for detecting the two- and three-feature changes in Experiment 1.

Error data. Figure 3 shows that the error rates for all conditions were less than 4.0%. An ANOVA, which evaluated type of change (2 vs. 3 features) and set size (4, 7, 10, 13, and 16), revealed neither significant main effects nor a significant interaction (all Fs < 1). Thus, it does not appear that interpretation of the RT data is compromised by speed–accuracy trade-offs.

Experiment 2

The purpose of Experiment 2 was to replicate the general pattern of results found in Experiment 1 using a different set of characters and a larger difference between the size of the discrepancies between the two displays. Although unlikely, it is always possible that the results of Experiment 1 are unique to the character set and the particular discrepancies used in the displays. Therefore, to establish the generality of the results found in Experiment 1, the basic experiment was repeated using the character set shown in Figure 2. The participants in Experiment 2 were required to detect two-feature and five-feature changes in displays that consisted of the digits *2*, *4*, and *8*. As Figure 2 shows, the two-feature change involved an *8* in the *A* displays that changed to a *2* in the *A′* displays, whereas the five-feature change involved a *4* in the *A* displays that changed to a *2* in the *A′* displays. As in Experiment 1, the efficiency of change detection was assessed in terms of the slopes of the resulting search functions.

Method

Participants. Eight undergraduate students at the University of Waterloo participated in the experiment. Each student had normal or corrected-to-normal vision and was paid $6.00 on completion of the 30-min experimental session.

Stimulus displays. Examples of the stimulus displays are shown in Figure 2. All aspects of the stimulus displays and all details regarding the presentation of the displays were the same as in Experiment 1, except for the fact that each display consisted of the digits *2*, *4*, and *8* rather than the letters *E*, *F*, and *L*.

Procedure. The procedure was the same as the procedure in Experiment 1.

Results and Discussion

RT. As in Experiment 1, a recursive procedure was used to remove the outliers in each cell before the RTs for the correct responses were analyzed. A total of 1.85% of the RTs were removed in this manner before the data were submitted to a two-factor ANOVA to assess type of change (2 vs. 5 features) and set size (4, 7, 10, 13, and 16).

Figure 4 shows the mean RT for each condition. Inspection of Figure 4 reveals that the general pattern of results was similar to the pattern of results found in Experiment 1. As in Experiment 1, the change involving the larger number of features, that is, five features, was more readily detected than the change involving the smaller number of features, that is, two features, $F(1, 7) = 36.64$, $MSE = 72{,}555$, $p < 0.01$, and search became more difficult with increased set size, $F(4, 28) = 79.74$, $MSE = 68{,}801$, $p < 0.001$. Importantly, the slope of the search function for detecting the larger, five-feature change (slope = 102.3) was shallower than the slope of the search function for detecting the smaller, two-feature change (slope = 142.1), $F(4, 28) = 3.64$, $MSE = 39{,}411$, $p < 0.02$. This difference between the slopes of the search functions for detecting the five-feature and two-feature changes is consistent with the general pattern of results found in Experiment 1. In both experiments, the change involving the larger number of features was easier to detect than the change involving the smaller number of features.[1] Thus, the results of Experiment 2 provide additional evidence that unattended changes play a functional role by directing attention to the location of a change.

Error data. Figure 4 shows that the error rates for all conditions were less than 4.0%. A two-factor ANOVA that assessed type of change (2 vs. 5 features) and set size (4, 7, 10, 13, and 16) revealed neither significant main effects nor a significant interaction (all $Fs < 2.13$, $p > .05$). Thus, it does not appear that interpretation of the RT data is compromised by speed–accuracy trade-offs.

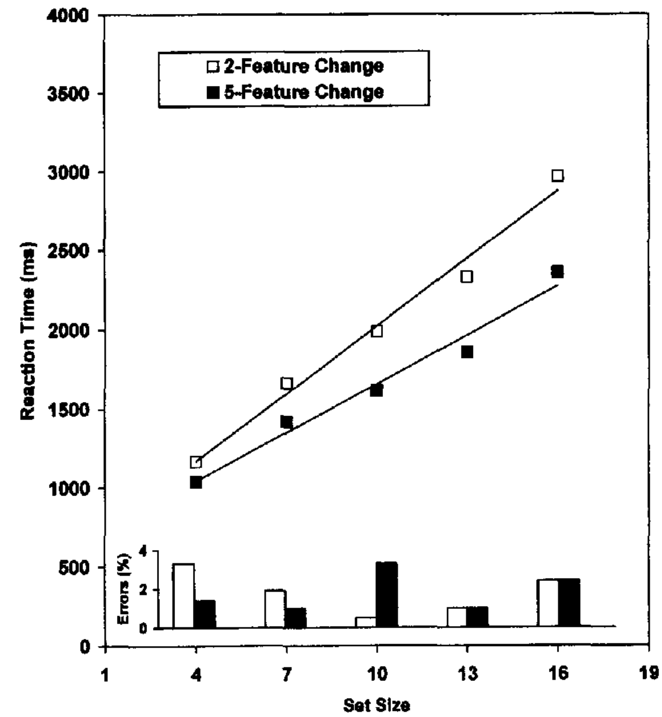

Figure 4. Mean reaction times and errors for detecting the two- and five-feature changes in Experiment 2.

Experiment 3

In Experiments 1 and 2, it was assumed that the 80-ms blank interval between the successive presentations of the *A* and *A′* displays was sufficient to eliminate any unique abrupt visual onsets that would attract attention to the locations of the changes. Although this assumption is reasonable, it is possible to argue that there may have been some visible persistence (cf. Coltheart, 1980) from one display to the next across the 80-ms interval that separated the successive presentations of the *A* and *A′* displays. If there was some visible persistence from one display to the next and if the larger changes (e.g., five features) led to more salient abrupt onsets than the smaller changes (e.g., two features), then the difference between the slopes of the search functions for detecting large and small changes found in Experiments 1 and 2 may have been due to abrupt visual onsets attracting attention to the location of the changes.

The purpose of Experiment 3 was to evaluate change detection under conditions that eliminated any possible influence of visible persistence from one display to the next. Experiment 3 was similar to Experiment 2, except that rather than presenting a blank screen during the 80-ms interval between the successive presentations of the *A* and *A′* displays, the luminance of the screen during the interval was the same as the luminance of the letters in the *A* and *A′* displays. It was assumed that the luminous screen during the temporal interval between the successive presentations of the displays would eliminate any visible persistence that could lead to unique abrupt visual onsets at the locations of the changes between the *A* and *A′* displays. Thus, if the differences between the slopes of the search functions for detecting large and small changes found in Experiments 1 and 2 were due to visible persistence from one display to the next, then no difference in slopes of the search functions should be found in Experiment 3.

Method

Participants. Eight undergraduate students at the University of Waterloo participated in the experiment. Each student had normal or corrected-to-normal vision and was paid $6.00 on completion of the 30-min experimental session.

Stimulus displays. The displays were similar to the displays used in Experiment 2 (i.e., Figure 2). The only exception was that the luminance of the screen during the 80-ms interval between the successive presentations of the *A* and *A′* displays was the same as the luminance of the letters in the *A* and *A′* displays.

Procedure. The procedure was the same as the procedure in Experiments 1 and 2.

[1] Although one might expect that the difference between the slopes of the search functions for detecting changes involving two versus five features should be greater than the difference between the slopes of the search functions for detecting changes involving two versus three features, such a comparison between experiments would be uninformative given that different stimulus sets were used in Experiments 1 and 2.

Results and Discussion

RT. As in the previous experiments, a recursive procedure was used to remove the outliers in each cell before the RTs for the correct responses were analyzed. A total of 2.05% of the RTs were removed in this manner before the data were submitted to a two-factor ANOVA to assess type of change (2 vs. 5 features) and set size (4, 7, 10, 13, and 16).

Figure 5 shows the mean RT for each condition. In general, the findings were very similar to the results of Experiment 2. The five-feature change was detected faster than the two-feature change, $F(1, 7) = 25.28$, $MSE = 107{,}127$, $p < 0.01$, and search became more difficult with increased set size, $F(4, 28) = 56.92$, $MSE = 164{,}578$, $p < 0.01$. Critically, the slope of the search function for detecting the five-feature change (slope = 126.8) was shallower than the slope of the search function for detecting the two-feature change (slope = 194.7), $F(4, 28) = 4.59$, $MSE = 108{,}588$, $p < 0.01$. Given the similar patterns of findings in Experiments 2 and 3, it appears that the luminance of the screen between the successive presentations of the A and A' displays has no important effect on the overall pattern of results. Thus, the results of Experiment 3 suggest that visible persistence was not an important factor in Experiment 1 and 2 and indicate that the guidance of focused attention by unattended changes observed in these experiments was not due to abrupt visual onsets attracting attention to the location of the changes.

Error data. Figure 5 shows that the error rates for all conditions were less than 5.0%. A two-factor ANOVA that assessed type of change (2 vs. 5 features) and set size (4, 7, 11, 13, and 17) revealed neither significant main effects nor a significant interaction (all $Fs < 1.59$, $p > .20$). Thus, it does not appear that interpretation of the RT data is compromised by speed–accuracy trade-offs.

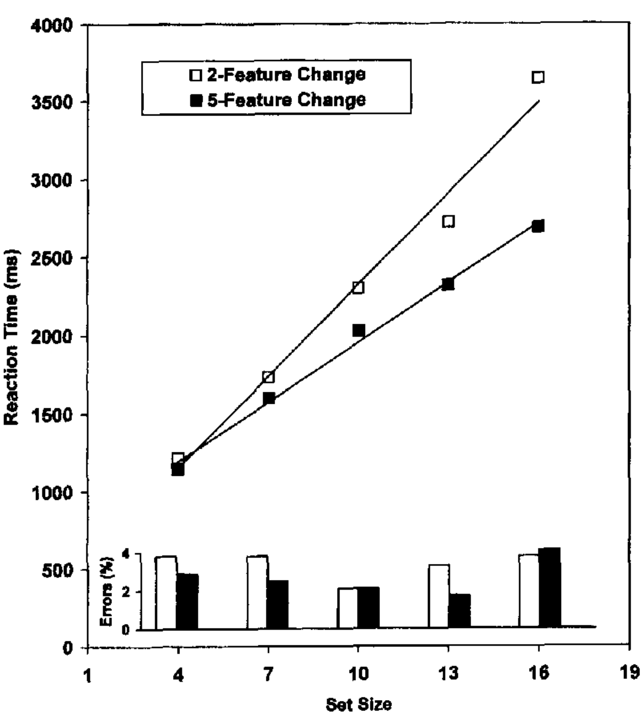

Figure 5. Mean reaction times and errors for detecting the two- and five-feature changes in Experiment 3.

General Discussion

The present experiments were designed to determine whether unattended changes between successive displays play a functional role in guiding attention to the location of the change. In all three experiments, the relative efficiency of preattentive processes in guiding attention to the location where the identity of an item changed between successive displays was assessed in terms of the slopes of the search functions for locating large and small changes. The basic underlying assumption was that more shallow slopes indicate more efficient preattentive guidance of focal attention. The consistent finding in all three experiments was that the slope of the search function for locating the change involving the larger number of features was shallower than the slope of the search function for locating the change involving the smaller number of features. This same basic pattern of results was found independent of whether the displays consisted of letters (Experiment 1) or digits (Experiments 2 and 3) and independent of whether a blank screen (Experiments 1 and 2) or a luminous screen (Experiment 3) was presented during the 80-ms interval that separated the successive presentations of the displays. Given that the larger changes between successive displays consistently led to more efficient preattentive guidance of focal attention, the present results provide strong support of the conclusion that unattended information regarding changes or discrepancies between successive displays plays a functional role in guiding attention to the location of these changes.

Previously, Rensink and his colleagues (O'Regan et al., 1999; Rensink, in press; Rensink et al., 1997) have suggested that attention to changes between two successive displays is guided by one of two possible processes. They suggest that when there is no temporal interval between successive presentations of the displays, attention is attracted to the location of a change by an abrupt visual onset at the location of the change. In contrast, when there is a short temporal interval between successive presentations, they suggest that attention is guided to the location of a change by a controlled, serial search process. Although both processes are undoubtedly involved at times in detecting the location of changes between successive displays, neither process is sufficient to explain the present results.

It is very unlikely that attention was attracted by abrupt onsets to the location of the changes in the present experiments. The strongest support for this conclusion comes from the results of Experiment 3. In Experiment 3, the luminance of the screen during the 80-ms interval that separated the successive presentations of the displays was the same as the luminance of the digits in the A and A' displays. This luminous screen effectively eliminated any visible persistence between the A and A' displays that could lead to abrupt onsets, which could in turn attract attention to the location of the changes. Nevertheless, the introduction of the luminous screen did not eliminate the difference between the slopes of the search functions for detecting two-feature and five-feature changes. Thus, given the results of Experiment 3, it seems unlikely that abrupt onsets played any role in the present experiments in attracting attention to the location of the changes.

It is also unlikely that attention was guided to the location of the changes in the present experiments solely by a controlled, serial search process. If the changes were detected solely by a controlled, serial search process, then any differences between the search functions for detecting changes involving different numbers of features should have been reflected in the intercepts rather than the slopes of the search functions. Given that the slopes of the search functions for detecting changes involving the larger number of features were consistently more shallow than the slopes of the search functions for detecting the smaller number of features, the results of the present experiments are not consistent with an interpretation that attributes change detection solely to a controlled, serial search process.

The conclusion supported by the results of the present experiments is that attention can be guided to the location of a change not only by abrupt onsets and by controlled, serial search, but also by unattended information regarding discrepancies or changes between displays. An important implication of this conclusion is that information regarding the unattended items in each display accumulates in memory across displays. This implication is consistent with previous findings showing (a) that there is memory for changes even when observers claim not to see the changes (Fernandez-Duque & Thornton, in press), (b) that observers often "sense change in a visual stimulus without seeing it" (Rensink, 1998, p. S631), and (c) that implicitly encoded contextual information facilitates visual search (Chun & Jiang, 1998). What the present findings add to these previous findings is evidence showing that unattended information regarding specific items in specific locations both accumulates in memory and is in a form that permits preattentive comparisons between displays that subsequently bias or guide attention to the location of the discrepant item. The present findings also show that the attentional guidance based on preattentive comparisons of specific items depends on the size of the discrepancy, whereby larger changes lead to more efficient preattentive guidance than smaller changes. The present results thus point toward the conclusion that unattended changes between successive displays play an important functional role in guiding the focus of attention to the location of these changes.

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