Abstract
Detection of an item changing its location from one instance to another is typically unaffected by changes in the shape or color of contextual items. However, we demonstrate here that such location change detection is severely impaired if the elongated axes of contextual items change orientation, even though individual locations remain constant and even though the orientation was irrelevant to the task. Changing the orientations of the elongated stimuli altered the perceptual organization of the display, which had an important influence on change detection. In detecting location changes, subjects were unable to ignore changes in orientation unless additional, invariant grouping cues were provided or unless the items changing orientation could be actively ignored using feature-based attention (color cues). Our results suggest that some relational grouping cues are represented in change detection even when they are task irrelevant. (137 words)
Change detection has been a useful tool to study visual attention and short-term memory in visual perception (Rensink, 2002; for a nice collection of studies, see Visual Cognition, 7, 2000). It creates surprising but convincing demonstrations of how visual representations are impoverished (Simons & Levin, 1997) and also how such representations can be enhanced by focal attention (Rensink, O'Regan, & Clark, 1997). It has become a standard paradigm for studying properties of visual short-term memory (VSTM; Luck & Vogel, 1997; Pashler, 1988; Philips, 1974). Most studies have focused on change detection of a collection of individual items, with an interest in how each item is represented and how its change is detected.

Change detection can also be used to probe the nature of relational encoding among items: how items are perceptually grouped and how such grouping is carried from perception to short-term memory. One approach is to cue attention to an element within a perceptual group, defined by proximity or connectedness, and test the success in detecting changes of items in the same or a different group (Woodman, Vecera, & Luck, 2003). Same-group items are better detected than are different-group items, suggesting that perceptual grouping is preserved in transferring information to short-term memory. Another approach relies on the principle of "encoding specificity" (Tulving, 1974) and varies the retrieval context such that across frames of changes, the context surrounding the critical change either matches or mismatches the context during encoding (Jiang, Olson, & Chun, 2000). Using the latter approach, we found that detecting location changes is unaffected by changes in the color or shape of the contextual items, but is disrupted by changes in the locations of the surrounding items. This suggests that the spatial relation formed by adjacent items is encoded and represented in VSTM, but surface features are not.

In this study we further pursue the representation of perceptual grouping in change detection tasks. What role does perceptual grouping play in detection of changes in item locations? Our own research in the past had suggested that perceptual grouping plays a significant role if it is relevant to the task, but can be largely ignored if it is irrelevant to the task. If, for example, subjects are asked to remember the locations of achromatic items and ignore the locations of chromatic items, then change detection is completely determined by changes of the chromatic items and is unaffected by changes of the achromatic items (Jiang et al., 2000). In this case, color grouping is relevant, and hence the target group (chromatic items) is attended and transferred into VSTM. If, however, color grouping is irrelevant, it is largely ignored. For instance, consider a set of red and green items forming two color groups - red items and green items. The perceptual organization (grouping) is preserved when these items maintained their colors across frames, but is changed if some of the red items swapped colors with some of the green items. Nonetheless, if subjects are asked to remember the locations of all the items, then location change detection is unaffected by such color swapping (Jiang et al., 2000). Thus, it appears that if color grouping is relevant to the task, then the target group is effectively selected and stored in VSTM; but if it is irrelevant to the task, then change detection of locations can proceed independently of changes in the perceptual organization of the display.

The purpose of our current study is to demonstrate that some types of perceptual grouping cues that are irrelevant to the task cannot be effectively ignored in change detection. We presented subjects with two dot arrays separated by a brief inter-stimulus-interval (ISI) of 1 s, and subjects were required to remember the locations of these dots and judge whether the two arrays occupied identical locations, or whether there was a change in one location. Using these displays, we had previously shown that change detection of dot locations was unaffected by the
color change of these items (Jiang et al., 2000). In the present study, we added a short line
segment interposing each dot. From the memory to the probe display, these line segments either
maintained their orientation, or changed orientation. A schematic sample of an orientation
change is illustrated in Figure 1.

Note that in this design, the locations of the dots were relevant while the orientations of
the line segments were not. Nonetheless, elongated lines tend to group by spatial proximity. The
change in their orientations produced a change in the proximity relations, and hence induced
changes in perceptual grouping. Can irrelevant perceptual grouping always be ignored in change
detection of item locations?

**Experiment 1**

**Method**

**Participants:** Participants were recruited from Yale University and Vanderbilt University.
Their ages ranged from 18 to 30. All subjects signed an informed consent form before the test
and were fully debriefed after the experiment. They had normal or corrected-to-normal visual
acuity, and normal color vision.

Ten observers were tested in Experiment 1.

**Procedure:** Each trial started with a white fixation point (0.3° x 0.3°) for 500 ms, which
was followed by an initial display containing 8 elements in randomly selected cells in an
invisible 8 x 8 matrix that subtended 17.5° x 17.5°. Each item was positioned at the center of a
cell. The initial display was presented for 400 ms, followed by a blank display of 1,000 ms. Next,
the probe display, containing 8 elements, was presented. Each element was a black dot (0.4° x
0.4°) with a white line segment (1.2° x 0.2°) interposing at its center. On 50% of trials, all of the
dots maintained their locations from the memory to the probe display. On the other 50% of trials,
one dot was randomly selected from the 8 and was relocated to a previously unoccupied cell.
Observers were required to press one of two keys to report whether they detected a change in the
locations. They were instructed that the location of an item was indicated by the black dot, and
they should ignore the white line elements.

In addition to location changes, each line segment either maintained its initial, randomly-
chosen orientation or changed its orientation by 45-90° (50% probability). Each participant was
tested in 12 practice and 80 experimental trials (80 – 2 location (change vs. nonchange) x 2
orientation (change vs. nonchange) x 20 cases).

**Equipment:** The experiment was programmed using MacProbe 1.88 (Hunt, 1994).
Observers were tested individually in a room with normal interior lighting. They sat at an
unrestricted distance from the computer screen of about 57 cm, at which distance, 1 cm
corresponded to 1° visual angle.

**Data analysis:** In this study we calculated A’ at each ISI as a measure of subject’s
sensitivity (Grier, 1971). We also measured percent correct and d’. The overall pattern of results
were the same whether A’, percent correct, or d’ were used. A’ was preferred as a measure of
memory accuracy (Donaldson, 1993).

**Results**

Mean A’ for change detection of dot location was 0.91 when the orientations of the
interposing lines did not change, and 0.76 when they changed. This difference was statistically
significant, t(9) = 3.48, p < .007. Thus, change detection of locations was significantly impaired
by orientation change of irrelevant line segments.

**Discussion**
Perceptual grouping and change detection

In change detection of dot locations, subjects were unable to ignore orientation change of interposing line segments. This suggests that at least some contextual mismatch between encoding and retrieval, irrelevant to the critical dimension of the task, could not be ignored.

We performed further experiments to clarify the conditions under which irrelevant orientation changes could and could not be ignored. Table 1 summarizes the results. These data ruled out some explanations of the disruption effect observed in Experiment 1. For example, (1) item rotation in general did not produce disruption in location change detection, as long as the item was not elongated (e.g., gratings and cross patterns); and (2) the amount of transient changes was not critical because rotation of cross patterns led to as much (or more) transient changes but did not disrupt performance. The fact that disruption was significant when the retention interval was only 50ms also suggests that the effect is tied to the perception of the stimuli and is not just a property of VSTM retention. In sum, it appears that orientation changes in the long axis of elongated objects were critical for the disruption of location change detection.

---------Insert Table 1 Here-------

Such disruption can be accounted for by the mismatch in perceptual grouping between the memory and the probe displays. Items in an array are not represented individually but relationally. Orientation change in elongated objects altered the global organization of the items. Figure 2 illustrates how the global organization of elongated items is affected by their orientations. Whereas lines on the left panel tend to be grouped horizontally due to spatial proximity (Palmer, 1999), after a 90° rotation, lines on the right panel tend to be grouped vertically, even though the center locations of each item did not change.

---------Insert Figure 2 Here-------

Perceptual grouping and change detection

If subjects are provided with an additional, explicit frame of reference that is constant across changes in orientation, then grouping by proximity should play a smaller role. The next experiment tests this hypothesis.

Experiment 2

Experiment 2 tested whether an added constant reference frame would reduce the disruption effect observed in Experiment 1. This additional reference frame was provided in two ways: line stimuli were presented within a regularly-spaced, visible grid (Experiment 2a), or, the centers of line stimuli were connected by chromatic links (Experiment 2b). Rotations of line stimuli orientation did not affect the location of each item within the grid, and the rotations did not change the shape of the chromatic links either. Thus the regular grid or the links provided constant information that is unaffected by line orientation change.

The constancy provided by the reference frames may help subjects ignore orientation changes. However, it is not obvious whether such constant, invariant cues are sufficient to reduce or remove the disruption effect. In fact, Experiment 1 showed that the presence of invariant information was not always sufficient. When dots were presented at the center of each line, rotating the line segments did not change the position of these salient dots (see Figure 1), yet subjects could not ignore the orientation change. In fact, the invariant central dots failed to reduce the disruption. Moreover, unpublished data from our lab revealed the same amount of disruption whether the line centers were marked or not. It is therefore of interest to find out whether other types of cues, such as the presence of a regular grid, may provide a constant reference frame that can reduce or eliminate the disruption effect.

Method
change produced a significant disruption on change detection when the lines were presented without the background grid, $t(15) = 4.45, p < .001$. In contrast, orientation change had no effect on performance when the lines were presented on a regularly-spaced background grid, $t(15) = 1.39, p > .15$. Thus, the presence of a background grid eliminated the disruption effect produced by line orientation change.

For Experiment 2b, ANOVA revealed a significant main effect of line orientation change, $F(1, 7) = 35.20, p < .001$, a significant main effect of the presence or absence of chromatic links, $F(1, 7) = 30.60, p < .001$, and a significant interaction between orientation change and chromatic links, $F(1, 7) = 16.49, p < .005$. Pair-wise t-tests showed that orientation change was disruptive both when the chromatic links were absent ($p < .001$) and when they were present ($p < .002$).

However, the significant interaction indicated that the presence of a constant chromatic link attenuated the disruption effect of orientation change.

Experiment 3

In Experiment 1 (and also Experiment 1b-1e, see Table 1) we have demonstrated that selective attention to one dimension of a stimulus (location) fails to filter out changes in another dimension (orientation) if there are multiple elongated items. This raises the question about whether the influence of orientation change is completely stimulus-driven or can be modulated by top-down attention. Studies directly addressing the relation between selective attention and perceptual grouping have shown that on the one hand, the spread of attention is affected by perceptual grouping (Egly, Driver, & Rafal, 1994; Lavie & Driver, 1996; Vecera & Farah, 1994), while on the other hand, top-down attention influences perceptual grouping (Peterson & Gibson, 1994a,b). Because perceptual grouping by line proximity appears to occur obligatorily, it is unclear whether it can be influenced by selective attention. In this experiment we test the effect of...
of selectively attending to one group of objects over another group, and measure the disruption of location change detection produced by orientation change of the attended versus the ignored group. Figure 4 (inset) shows a sample of a display.

Each display contained two sets of items – red dots with an interposing red line segment and green dots with an interposing green line segment – randomly intermixed on a 10x10 invisible matrix. Subjects were instructed, in different blocks, to attend either to the red items or to the green items and to perform location change-detection of the attended group of items. To test the effect of selective attention, we independently varied the probability of orientation change for the attended and the ignored sets. If subjects can effectively attend to the instructed group of items and if selective attention modulates which items enter perceptual grouping, then orientation changes of the attended group should have a larger effect than orientation changes of the ignored group. However, if the influence of orientation changes is completely stimulus driven, then we may not observe an effect of selective attention.

Method

Participants: Seventeen observers participated in this experiment.

Materials: Each display contained 8 red items and 8 green items, randomly intermixed on a 10x10 invisible matrix (19°x19°). Each item was a filled dot (0.4°x0.4°) interposed with a line segment (1.2°x1.2°) that had one of four possible orientations (0°, 45°, 90°, or 135°).

Procedure: Subjects were tested in 10 practice trials and 4 blocks of experimental trials containing 48 trials each. Before each block they were instructed to attend either to the green or to the red items and to perform a location change detection on the filled dots. Each trial started with a fixation point of 400ms, followed by a memory display (8 red items and 8 green items).

The memory display was presented for 400ms and erased. After a blank interval of 1s, a probe display was presented until response. The probe display also contained 8 red and 8 green items. Half of the time one of the attended items changed its location to a previously blank location, and half of the time the attended items maintained their locations. The ignored items never changed locations. Subjects were asked to press a right key if they detected a location change and a left key otherwise. They were told to ignore the oriented lines and their orientation changes. The attended items changed their orientations on 50% of the trials. Furthermore, the ignored items also changed their orientations on 50% of the trials.

All the factors tested in this experiment were independently manipulated. Thus, subjects were tested in a total of 192 experimental trials, which can be broken down as: 2 attended colors (red vs. green) x 2 location changes (change vs. no change) x 2 attended items’ orientation (change vs. no change) x 2 ignored items’ orientation (change vs. no change) x 12 cases.

Results

We pooled data across blocks of attending to red and blocks of attending to green and measured A’ separately for four conditions: both attended and ignored groups maintained their orientations (both same), ignored group changed orientations (ignored different), attended group changed orientations (attended different), and both groups changed orientations (both different). Figure 4 shows the results.

An ANOVA on attended group and ignored group revealed a significant main effect of attended group, F(1, 16) = 5.78, p < .029, showing lowered A’ for location change detection when the attended group of items changed orientations. The main effect of ignored group was not significant, F(1, 16) = 1.10, p > .30, suggesting that performance was not disrupted by orientation changes in the ignored group. The interaction between attended group and ignored
group was not significant, $F(1, 16) = 2.41, p > .14$. Planned contrasts showed that orientation change in the attended group alone was sufficient to disrupt performance, $F(16) = 2.47, p < .05$. Nonetheless, orientation change in the ignored group alone produced a marginally significant reduction in performance, $F(16) = 2.22, p < .081$. This could be due to attention leaking to the ignored items, or to a stimulus-driven effect of obligatory grouping of every item on the display. Thus, even though this experiment did not allow us to completely rule out bottom-up effects of orientation change on location change detection, it provided clear evidence that such effects were significantly modulated by selective attention.

Experiment 4

Two factors jointly contribute to the effect of orientation change on location change detection. First, the spatial relation among items is obligatorily encoded in representation of multiple locations (Jiang et al., 2000). Second, when constructing the global configuration, subjects are unable to extract just the pattern formed by the dots. Instead, the imaginary contour formed by the elongated objects becomes part of the global pattern, which changes when the objects rotate. In Experiment 2 we tried to break the representation of the global pattern by connecting the center of the dots, or by presenting a regular grid that serves as an external frame of reference to represent individual dots. This largely reduced the orientation change effect.

In this experiment, we further eliminate the need to encode the global configuration by informing subjects the single item that might change location [1]. The informative cue serves to narrow the focus of spatial attention to a single location, removing the necessity to represent all the items and their configuration.

Method

Participants: Six observers were tested.

Materials: Each display contained 8 dots that were interposed by a short line segment (see Experiment 1 & Figure 1). The first display was presented for 150 ms and erased. One second later, another display was presented until a response was made. The first display was presented briefly to eliminate eye movement.

Design. Subjects were tested in two conditions: diffused attention and focal attention (Figure 5). In the diffused attention condition, the first display contained 8 black dots and the second display contained 1 black dot and 7 white dots. Subjects were asked to decide whether the black dot on the second display was at one of the previous 8 locations or not. Because they had to monitor all dots on the first display, attention was diffuse, so subjects would need to encode the individual locations and their global configuration. In the focal attention condition, the first display contained 1 black dot and 7 white dots, so was the second display. Subjects were asked to decide whether the black dot on the second display was at the same location as the one on the first display. Because only a single location needed to be extracted and monitored from the first display, attention was narrow, so there was no need to encode the global configuration. Figure 5 shows an example of the display.

Subjects were tested in 20 practice trials and 160 experimental trials. These included a factorial design of three factors: extent of spatial attention (diffused vs. focal), location change (same vs. different), and orientation change (same vs. different). Like Experiment 1, an orientation change meant that all items rotated by 90°, including the item(s) that the subjects were monitoring.

Results and Discussion

---Insert Figure 5 Here---
Results are shown in Figure 5. We calculated A’ as well as mean RT from individual subjects’ median RT (for correct trials only). ANOVA on attention and orientation change showed that performance was better when subjects monitored one location than eight, $F(1, 5) = 39.59, p < .001$, and when the orientation of the irrelevant line segments stayed the same, $F(1, 5) = 12.81, p < .016$. There was also a significant interaction between set size and orientation change, $F(1, 5) = 18.72, p < .008$, suggesting that the effect of orientation change was modulated by how diffuse spatial attention was. Orientation change disrupted performance only when subjects attended to all locations, $t(5) = 4.34, p < .007$, but not when they focused on one location, $t(5) = .99, p > .35$.

A similar pattern of results is seen in RT. ANOVA showed significant effects of set size, $F(1, 5) = 26.93, p < .003$, orientation change, $F(1, 5) = 39.83, p < .001$, and their interaction, $F(1, 5) = 9.44, p < .03$. Orientation change lengthened RT when subjects monitored all locations, $t(5) = 7.76, p < .001$, but not when they focused on one location, $t(5) = 1.32, p > .20$.

**General Discussion**

This study provides a compelling demonstration that the perceptual grouping of individual items can significantly affect change detection, even when subjects are instructed to ignore grouping. When subjects had to focus on change detection of one dimension – the spatial location of elongated items – they were unable to ignore changes in another dimension – the orientations of the items. We believe that this is because changes in the orientations of elongated objects altered their global perceptual organization. This disruption can be reduced by an invariant frame of reference, such as a regularly spaced background grid (Experiment 2a), and by actively using color feature cues to ignore the group of items that underwent orientation changes (Experiment 3), or by narrowing the focus of attention to a single item (Experiment 4).

However, the presence of constant information was not always sufficient (Experiment 1), and the task demand to ignore orientation change of the attended set of items was not always effective.

The disruption of location change detection by orientation change is an outcome of two interrelated processes. First, when multiple locations need to be retained briefly, the visual system does not simply encode each individual spatial location in an egocentric or environment-based frame of reference. Instead, the pattern formed by all the elements is obligatorily encoded and retained. A change in the configuration of items severely disrupts change detection of individual locations (Jiang et al., 2000; Santa, 1977). Configural encoding is modulated by attention: only items that are actively attended to become part of the configuration (Jiang et al., 2000). As a result, changes to irrelevant locations are negligible (Experiments 3 & 4).

Related to configural processing, perceptual grouping influences how a configuration may be formed. Thus, manipulations that might change the perceived configuration can potentially disrupt representation of the locations. Under many conditions, selective attention can override the potential disruption produced by irrelevant changes. For example, differences in color grouping from memory to probe displays were negligible during location change detection. This suggests that perceptual grouping by color does not influence the spatial configuration of items. The special case that cannot be disregarded is the orientation change in the long axis of elongated objects, even when the center of these objects was clearly demarcated.

Configural encoding alone cannot explain the effects of orientation change. This is because the configuration formed by the dots remained the same across the two displays. The results can only be accounted for if the configuration included not just the center dots, but also the long axis. Orientation change alone also fails to explain the disruption effect, because orientation change of a single item (Experiment 4), irrelevant items (Experiment 3), or items
encoded within an environment-based frame of reference (Experiment 2a), did not influence change detection of locations. Such effects, therefore, must arise from the interaction among elongated objects in multi-element displays. Namely, the proximity relations are no longer preserved when the long axes of these objects rotate.

Although we did not test how change detection of locations may be influenced by all kinds of grouping changes, the above analysis suggests that only the kind of grouping cues that influences the relative spatial location among items will have an effect. Grouping cues that affects similarity without changing perceived proximity, such as color grouping, do not influence location change detection. By this logic, the current paradigm provides a tool to quantify whether certain grouping cues influence our perception of spatial locations. For example, items that share common regions (Palmer, 1992) might be considered as belonging to the same perceptual group. But would people perceive items within a common region as spatially closer than items in different regions? One could investigate such questions by testing location change detection, and varying the contours that define common regions from one display to another, and observe how such changes in perceptual grouping affect location judgment.

In conclusion, our study provides further support that items are represented in a relational manner in change detection (Jiang et al., 2000). Perceptual grouping between items can affect how each item is represented, even when the grouping is task irrelevant. Whether or not grouping as defined by other kinds of visual features is also represented in change detection remains to be seen.

Reference


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Rensink, R.A, O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. Psychological Science, 8, 368-373.


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Table 1. Location change detection (A') using various stimuli. A' ranges from 0.5 to 1: 0.5 corresponds to chance performance and 1.0 to perfect performance.

<table>
<thead>
<tr>
<th>Exp</th>
<th>Stimuli</th>
<th>Type of item change from memory to probe displays</th>
<th>A' with change</th>
<th>A' w/o change</th>
<th>N</th>
<th>P level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1b</td>
<td>—</td>
<td>Rotation; ISI = 1000 ms</td>
<td>0.73</td>
<td>0.87</td>
<td>7</td>
<td>.006</td>
</tr>
<tr>
<td>1c</td>
<td>—</td>
<td>Rotation; ISI = 50 ms</td>
<td>0.83</td>
<td>0.98</td>
<td>7</td>
<td>.002</td>
</tr>
<tr>
<td>1d</td>
<td>—</td>
<td>Addition or deletion of line segments</td>
<td>0.81</td>
<td>0.88</td>
<td>8</td>
<td>.005</td>
</tr>
</tbody>
</table>
| 1e  | — | Length change
Same subjects: rotation | 0.88 | 0.95 | 6 | .007 |
| 1f  | — | Rotation | 0.88 | 0.88 | 11 | > .50 |
| 1g  | — | Rotation | 0.86 | 0.88 | 10 | > .35 |
| 1h  | — | Color change | 0.88 | 0.89 | 7 | > .50 |
| 1i  | — | Shape change | 0.91 | 0.90 | 7 | > .50 |
| 1j  | — | Size change | 0.81 | 0.84 | 7 | > .25 |

** With comparable amount of end point changes, rotation produced a larger disruption effect than length change.
Figure 1. A schematic sample of displays used in Experiment 1. This sample shows a trial in which a dot changed its location, and the line segments all changed orientations. Not shown are control trials in which the line segments maintained their orientations.

Figure 2. Change in the orientation of the long axis of an item leads to a change in perceptual grouping.

Figure 3. Results from Experiment 2. Error bars indicate standard error of between-subject variation.

Figure 4. Results from Experiment 3. A sample display is shown in the inset of the figure. Red (shown as black items on this figure) and green items (shown as white items on this figure) were randomly intermixed on the display. Error bars indicate standard error of between-subject variation.

Figure 5. Sample displays and results from Experiment 4. Subjects monitored the location of black dots. Error bars indicate the standard error of the difference between orientation-same and orientation-different.
Figure 2.

Figure 3.
Figure 4.

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Figure 5.