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# Failure to detect changes in color for lines rotating in depth: the effects of grouping and type of color change

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**Abstract**

A new technique for measuring change detection was introduced in which contours rotating in depth around a vertical axis (in a computer display) could be altered in color as they passed through their point of minimum extension (the median plane) where a thin static vertical occluder hid the change. Sets of five or six contours were either strongly grouped (similar in length, orientation and spacing) or weakly grouped (of variable length, orientation and spacing). Changes consisted of one line changing to a new color or else two lines swapping colors. The measure was the proportion of missed changes. When subjects were not instructed to look for change almost no changes were reported although subjects were told beforehand that they would have to describe the configuration after viewing it. When subjects were instructed to look for changes, it was found that detection of color change was significantly better for strongly grouped lines. It is proposed that grouping, by reducing redundancy, also reduces attentional demands with respect to the properties on which it is based, making it easier to attend to and therefore detect changes in other properties. We found that it was much easier to detect the introduction of a new color than to detect a swap between two existing colors. It is hypothesized that swap-type changes were harder to detect because they required attention to a conjunction of position and color. 

*Keywords:* Perceptual grouping; Change blindness; Attention

## 1. Introduction

Recent research demonstrates that people frequently fail to detect changes in a viewed scene, when transients are masked. (Phillips, 1974; Pashler, 1988; Grimes, 1996; McConkie & Currie, 1996; Simons, 1996; Rensink, O'Regan & Clark, 1997; Simons & Levin, 1998). This phenomenon has been labeled change blindness.

Rensink et al. (1997) claimed that a change to an item can only be detected if attention is focused on it immediately before and after the change occurs. Simons and Levin (1998) however, found that even changes to items that are the center of attention could go unnoticed. They asserted that while attention is necessary for change detection it is not sufficient, claiming that 'successful change detection probably requires effortful encoding of precisely those features or properties that will distinguish the original object from the changed object.' (Simons & Levin, 1998). The issue of what factors can optimize detection of change among a set of items, presumably by facilitating attention and encoding, has important practical and theoretical consequences.

### 1.1. Grouping and the detection of change

One issue that has not yet been addressed in relation to change blindness is the effect of perceptual grouping. Perceptual grouping refers to the fact that elements are organized into units (Wertheimer, 1923; Koffka, 1935). It is widely supposed that it is these units rather than the elements themselves which become the objects of further processes, such as object recognition (Barlow, 1961; Nakayama, 1990), visual search (Treisman, 1982; Watson & Humphreys, 1999) and motion/depth processing (Gillam, 1972, 1990). The traditional view of grouping 'the whole is different from the sum of its parts' might lead to the presumption that when attention is focused on a group the parts lose their individual

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identity (Wertheimer, 1923; Koffka, 1935; Treisman, 1982). If so change in an element might be more difficult to detect as a result of its grouping with other elements.

Considerable research has supported the view that attention is directed towards perceptual groups as defined by the Gestalt laws of organization (Fox, 1978; Kahneman & Henik, 1981; Prinzmetal, 1981). For example it has been shown in search tasks that when visual distracters are grouped with a target item interference is high (Banks & Prinzmetal, 1976; Driver & Baylis, 1989; Kramer & Jacobson, 1991; Baylis & Driver, 1992).

On the other hand, there is evidence that has been taken to support the view that attention can be switched more quickly between items located on a single surface than between items on different surfaces (Egly, Driver & Rafal, 1994; Chen, 1998). If this principle is applied to grouping it might lead to the prediction that a change for elements that are part of a group would be easier to detect, because attention can more quickly be switched between them.

There are thus two possible opposite predictions for the effect of grouping on change detection. On the one hand if grouping makes it more difficult to direct attention to the properties of the individual elements which constitute the group, an element change within a group would be less likely to be noticed unless it alters an emergent feature, that is, a property of the group as a whole. The alternative possibility is that perceptual grouping, by allowing the fast spread of attention within the group, may allow for more effective attentional allocation to and encoding of the individual items that make up the group. In this case it would be easier to detect changes when items are strongly grouped. The present studies tested these predictions for several types of change described below.

### *1.2. Comparing a change in identity with a change in location*

An additional interest of our study was the detectability of different types of change. There is considerable evidence to suggest that information regarding the identity of a feature is more likely to be encoded than the location of that feature in the visual field. (Townsend, 1973; Mewhort, Campbell, Marchetti & Campbell, 1981; Irwin, 1991, 1992; Irwin & Andrews, 1996). For instance, Irwin (1992) found that even though the ability to retain information across eye saccades is poor, people were better at remembering information about identity than about location. There is also support for a distinction between the representation of location and identity from studies on illusory conjunctions. When subjects are asked to describe a number of objects, features are sometimes combined incorrectly (Treisman & Schmidt, 1982; Treisman & Paterson, 1984; Irvy & Prinzmetal, 1991; Lasaga & Hecht, 1991; Prinzmetal, Henderson & Irvy, 1995) suggesting that location information is represented less accurately than identity information. Simons (1996) found that changes made to the spatial layout of items are easier to detect than changes made to their identity or their position within an existing layout, but he did not distinguish between identity and position.

In the present studies changes in color will be introduced in two ways. Either one item of the set of elements will change to a color not previously present (introducing a new item identity) or else two of the items will swap their colors (causing a change in the positions of existing item identities). The detectability of these two types of change will be compared both for strongly grouped and for weakly grouped elements.

### *1.3. A new method for measuring change detection*

In our investigations we used Gillam's criterion of perceptual grouping which also has considerable advantages in the investigation of change blindness. Her technique presents observers with several contours rotating in depth around a common central axis. Contours are oblique and thus subject to the kinetic depth effect (Wallach & O'Connell, 1953) but because the projection used is a parallel one the direction of rotation is ambiguous. The stimulus is thus consistent with either clockwise or counterclockwise rotation. Grouping is measured by the degree to which the ambiguity of two or more contours with respect to direction of rotation is resolved in common so that the contours appear to rotate in the same direction and reverse together. Gillam and colleagues have conducted a series of studies in which several contours were presented rotating in phase around a common vertical or horizontal axis under parallel projection (Gillam 1972, 1975; Gillam & McGrath, 1979; Gillam 1981; Gillam & Grant, 1984; Gillam & Broughton, 1991). Grouping was considered inversely proportional to the time during which any two such contours appear to rotate in the opposite direction to each other (fragmentation time). It was found that grouping was influenced by a number of parameters of a pair of lines including, their relative orientation, the ratio of the separation of the contours to their line length, their overall orientation with respect to the axis of rotation and the presence of a surrounding frame. Also grouping of entire sets of lines can be enhanced by their convergence to a vanishing point, or by collinearity of their terminations.

In the present study observers viewed either a strongly grouped or a weakly grouped set of multi-colored planar lines according to criteria established by Gillam's research. The lines were presented on a computer monitor in simulated parallel projection of rotary motion in depth around a vertical axis. Changes in color were made during the rotation which subjects were required to detect.

To investigate change blindness the actual change event must be hidden from the observer since the motion transient signals associated with a physical change tend to attract attention and make the change event obvious. This has been accomplished by various methods in the past, such as the flicker technique developed by Rensink et al. (1997), eye saccades, (Grimes, 1996) and scene cuts in films (Levin & Simons, 1997). Our method removes transient signals in the following way. The contours are in phase with respect to rotation so that they all pass through the median plane and the frontal plane at the same time. When the rotating lines are in a perpendicular position relative to the observer (in the median plane) they are at their minimum projected width. At this point a change is made in color to one or more of the lines. This change is hidden by a thin static vertical bar on the axis of rotation at the median plane behind which the lines appear to briefly pass. It seems perfectly natural for the lines to pass behind a fixed occluder and the appearance of smooth continuous motion is not interrupted.

Sets of no more than six lines were used, that were either equal in length and parallel (strong group) or were different lengths and different orientations (weak group), as shown in Fig. 1. The advantage of using very simple stimuli is that it allows for a more stringent control over stimulus factors than has been conventional in this area.

An advantage of this technique is that participants are observing an event (rotary motion in depth) which not only maintains their attention but also requires it, since ambiguity must be resolved (although the observer is not aware of it), in order to see rotation at all.

Fig. 1. The stimuli used in Experiment 1. The lines rotated in depth around a common vertical axis against a black background, (a) shows the strongly grouped set of lines and (b) the weakly grouped set of lines.

Another advantage of the technique is that it provides a very natural way for investigating the effect of expectation on the detection of change. Levin and Simons (1997) found that when participants were expecting change, more changes were noticed than when changes were not expected. Since the present technique involves a dynamic event, subjects can plausibly be asked to view the rotating lines with general instructions to observe the stimuli carefully so as to report later what they saw but without specific mention of the possibility of color changes. In each of the experiments to be reported, detection of color changes is first assessed in this way with participants naive to the possibility of change and then later, in the main experiment, when they are expecting color changes and are required to look for them.

## 2. Experiment 1

There were four experimental conditions: (a) strong group with a 'new' color introduced as the change; (b) strong group with a swap in two existing colors; (c) weak group with a 'new' color type change; and (d) weak group with a swap in colors.

### 2.1. Method

#### 2.1.1. Participants

Twenty-five undergraduate psychology students participated and received credit for their time.

#### 2.1.2. Stimuli

The figures consisted of five differently colored lines. The particular colors to be used for a given figure were chosen at random from a collection of seven colors including red, blue, aqua, yellow, green, purple and gray. These colors were matched for luminance using flicker photometry.

The strongly grouped stimuli consisted of five parallel lines of equal length. Each line formed an angle of 25° to the horizontal and had a length of 4.6 cm (5.3°) on the computer monitor. The weakly grouped set consisted of five lines of different lengths and different angles. The angles of each line was selected at random with the restriction that none was greater than 40° from the horizontal. The lengths of the lines were 4.0, 3.2, 5.8, 3.3 and 3.8° in that order (see Fig. 1). Pilot studies revealed that the strong group had virtually no fragmentation and the weak group fragmented 27.51% of the time, using Gillam's criterion that at least one line was perceived as rotating in the opposite direction from the rest.

In both groups the lines rotated around a central vertical axis at a speed of 45°/s. The two grouped sets occupied the same area on the computer screen ($9 \times 5.5$

$cm^2$) subtending a visual angle of vertical angle of 10.29° and a horizontal angle of 6.3°.

A trial consisted of the presentation of a set of rotating lines (either the strong or weak group) in which the *same* change occurred seven times. The change involved either the swap of two colors within the figure (swap) or the changing of one color to a new color (new). The changes occurred randomly throughout the trial but always when the lines passed through the vertical axis/median plane and were at their minimum extension. The static occluder which hid the actual change event was red–brown in color and 7 × 0.2 cm on the screen subtending a vertical visual angle of 8° and a horizontal angle of 0.6°. The lines began rotation from a position in the median plane.

#### 2.1.3. Apparatus

The stimuli were displayed on a Mac7220 with a 15-in. multiple scan 720 display monitor. Participants responded on the single mouse button placed in front of them.

#### 2.1.4. Procedure

Forty trials (ten per condition) were presented for a maximum duration of 74 s during which the lines passed through the median plane, where a change was possible, 20 times. There was at least 8 s between changes to allow participants ample time to detect and respond to the change. As soon as the subject reported the change the trial was terminated. There were two catch trials during which no changes occurred. If participants responded during these trials their entire data was eliminated from the analysis. Subjects were also asked to report on the nature of the change after it was detected. These procedures in combination with the instructions (see below) were considered sufficient to discourage guessing.

#### 2.1.5. Blind trials

Prior to conducting the actual experiment participants were given two blind trials, one with the weakly grouped set of lines and one with the strongly grouped set. These trials lasted for 60 s during which five changes occurred. Before viewing the figures participants were told to observe the stimuli carefully because when each trial ended they would be asked to describe what they saw in detail. Color changes were not mentioned. Responses were recorded with a special note as to whether or not color changes were reported.

#### 2.1.6. Main experiment

Following the two blind trials the experiment commenced. Participants were told that a change would occur in some of the trials and that their task was to press the mouse button when they noticed a change in color. It was made clear that they had to be absolutely sure that they saw a change before they responded and were warned that they may be stopped and asked to report on the change they saw. They were also instructed to count out loud from 1 to 100 whilst viewing the stimuli to suppress articulation and prevent the explicit verbal encoding of stimuli.

When the experiment was completed participants were asked to make comments. All comments were recorded.

### 2.2. Analysis, results and discussion

There were three criteria for excluding data provided by participants. First, if any participant made a response in either one or both of the catch trials. Second, if a participant responded before any change was made in a trial. Finally, if participants gave incorrect responses regarding the changes they were seeing. Four of the 25 participants were excluded for one of these reasons.

#### 2.2.1. Blind trials

Averaging across the strong and weak groups for all participants, changes were undetected 84% of the time. This indicates that people are highly likely to miss changes when they do not expect them to occur, even when the same change occurred five times throughout the trial.

#### 2.2.2. Change detection

In the main experiment participants were told that they were looking for changes in color. Under these instructions the average percentage of misses was 18.78%. Comparing this percentage with the percentage of misses in the blind trial (84%), it is clear that expectation had a major influence on the detection of change.

The means and standard errors for the main experiment are shown in Fig. 2. The difference between the overall means for the strong and the weak group is small (only 0.17%) and a two-way ANOVA found no significant main effect of grouping [$F(1,20) = 0.18$]. However, there was a significant effect for the type of change [$F(1,20) = 47.41$; $P < 0.05$]. According to the cell means there are more misses in the swap condition (25.95%) than the new condition (11.29%), averaged across level of grouping. This large effect indicates that people encode information about what colors are present in the stimuli better than information about their positions indicating that the presence of a color and its position are encoded independently.

There was a significant interaction between the degree of grouping and the type of change [$F(1,20) = 11.12$; $P < 0.05$]. There was a larger effect of change

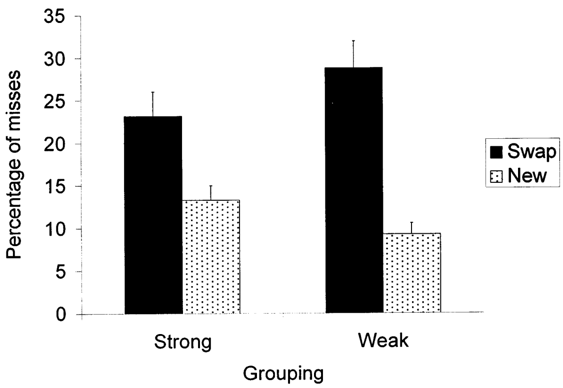


Fig. 2. A graph of the means for the different changes (swap and new) made within a strong and a weak group ( Experiment 1).

type for the weak group than for the strong group. A post-hoc analysis found no difference between the grouping conditions for the new-type change [$F(1,21) = 0.346$]. However it was easier to see the swap when the lines were strongly grouped (23.14%) than when they were weakly grouped (28.76%) [$F(1,21) = 4.53$; $P < 0.05$].

These findings support the view that for changes which are more difficult to detect, (swap conditions) grouping facilitates the detection of change.

In this Experiment however the same color change occurred seven times so it is not surprising that it was detected eventually with a relatively high probability. Experiment 2 was designed to investigate the effect of grouping when the detection of change was made more difficult.

## 3. Experiment 2

This experiment used the same basic method as Experiment 1, but used a different sequence of changes. Unlike Experiment 1 in which the same change occurred repeatedly throughout the trial, in Experiment 2 different changes (involving different lines and different colors) occurred throughout the trial. This procedure was expected to make the task of detecting change more difficult. Changes were of the same type as Experiment 1 (i.e. a swap between existing colors or the introduction of a new color).

### *3.1. Method*

The methods for Experiment 2 were identical to those employed in Experiment 1, with the following exceptions.

#### *3.1.1. Participants*

Twenty-two first year psychology students participated for course credit.

#### *3.1.2. Stimuli*

The figures to be used were the same as used in Experiment 1 except for the addition of one extra line. Hence, in the strongly grouped set there were six lines of equal length and parallel to each other. Lengths and angles were the same as in Experiment 1. The weakly grouped set had an additional line placed below the others with a length of 3.8 cm. The occluder was 9.1° in the vertical dimension and 0.6° in the horizontal dimension.

The types of change were the same as in Experiment 1 (i.e. swap and new). However, in this experiment a trial consisted of the presentation of a set of rotating lines (either strongly grouped or weakly grouped) in which either six or seven *different* changes occurred.

#### *3.1.3. Procedure*

The same four conditions were examined as in Experiment 1. (swap/new colors combined factorially with weak/strong group). However, there were only four trials per condition. Each trial lasted for 80 s and within each trial either six or seven different changes occurred out of a possible 20. Over all trials participants were exposed to 28 changes for each condition. A slightly different number of changes was used from trial to trial to ensure that participants would not learn how many changes were to occur.

Prior to the experiment participants were given two blind trials. The basic procedure for the blind trials was identical to that of Experiment 1. Participants viewed a strongly grouped set and a weakly grouped set for 60 s. However five different changes occurred during this period.

Participants were not stopped during the experiment to report on the changes that they saw, as this would have been disruptive to the task. To minimize the inclusion of accidental or other invalid responses reaction time distributions were used.

All reaction times for every response, across all participants, were collated. From this the frequencies of different reaction times were calculated. These are shown in Fig. 3.

Based on these data it was decided to use only responses occurring within 3 s of the change as this incorporated most of the responses while eliminating outliers unlikely to reflect responses to real change.

### *3.2. Results and discussion*

#### *3.2.1. Blind trials*

In 75% of the trials not one of the five different changes were noticed. Once again there is strong support for the view that when naive to the possibility of change people are unlikely to perceive them, even when paying close attention to the stimuli in which the changes occur.

### 3.2.2. Change detection

Fig. 4 shows the means and standard errors for each condition. The number of misses are expressed as percentages. The percentage of overall misses (i.e. across all conditions) in Experiment 2 (45%) was markedly higher than in Experiment 1 (19%). It was generally more difficult to see changes when there are six lines in the figure and when different changes are involved in each trial.

Unlike the findings of Experiment 1 there was a significant main effect of grouping on change detection [$F(1,21)=4.57$; $P<0.05$]. It was more difficult to notice changes when the lines are weakly grouped (47.5% misses) as opposed to when they are strongly grouped (43.2% misses). It can be concluded that even when the task of detecting change was made more difficult it was easier to notice the changes made to the strongly grouped set of lines.

The main effect of change type was also significant [$F(1,21)=35.57$; $P<0.05$]. As in Experiment 1 it was much more difficult to detect a swap in colors than to detect a new color. The interaction between grouping and type of change was not significant [$F(1,21)=1.05$] although there appears to be a stronger effect of grouping on the swap conditions than on the new in line with the findings of Experiment 1.

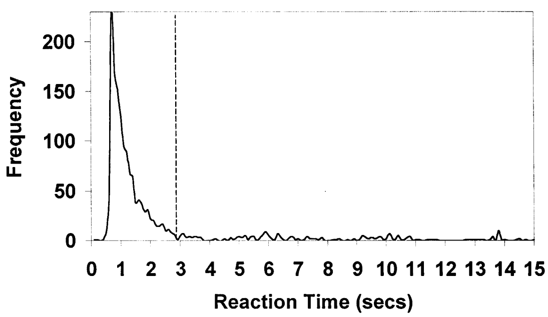


Fig. 3. The frequency of reaction times in Experiment 2. The time between any two changes ranged from 8 to 16 s. Most responses were made within 3 s of a change occurring.

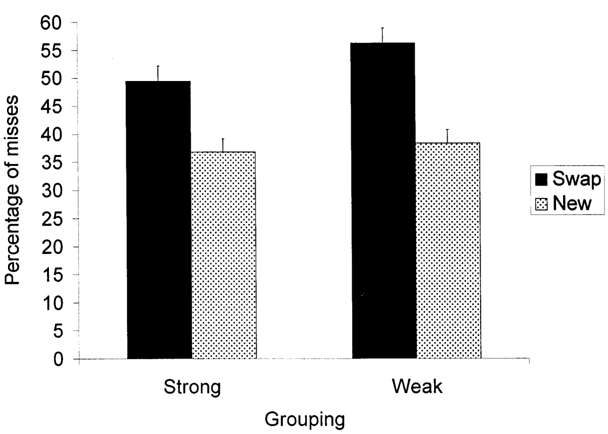


Fig. 4. A graph of the means and standard errors for Experiment 2.

## 4. General discussion

Our results have shown an influence of the way visual information is organized on the ability to detect changes in visual arrays. In addition they have shown that it is much easier to detect the presence of a new feature than to detect a swap in the positions of existing features. From both experiments it can be concluded that especially for the more difficult to detect 'swap' changes the perceptual system relies to some extent on a strong degree of grouping to aid in the detection of change.

It will be assumed in what follows that differences in detecting change when it occurs reflect the ease with which attention can be allocated to items and their features. Since the event to be encoded was common to the poorly grouped and the weakly grouped set it is unlikely that ease of encoding is responsible. Our findings do not support the view that the grouping of a set of items makes it more difficult to pay attention to the individual features. In visual search studies Rensink and Enns (1995) concluded that grouping leads to 'preemption' of the segments by the group so that the latter are not available. Treisman (1982) asserted that 'when we attend to the global configuration, each local element loses its separate identity, except insofar as it contributes to the identity of the whole.' The contrary is true in our studies. The grouping of a set of items made it easier to attend to the color of individual components. We suggest that this can best be accounted for by assuming that grouping is not of items but of item features. A set of items could be grouped for one set of features (e.g. orientation) but not another (e.g. color). This is in accordance with the notion of grouping as the reduction of redundancy (Attneave, 1954; Barlow, 1961; Gillam & Grant, 1984; Nakayama, 1990). Similarly Gillam and Grant (1984) argued that grouping can occur with respect to some *responses* and not others. In the present case elements are grouped (in the strong group condition) with respect to orientation and length. Subjects are observing an event, rotary motion in depth, which requires that they pay some attention to transformations in orientation and length (Wallach & O'Connell, 1953). Therefore insofar as these features are grouped, attentional demands are reduced. It is no longer necessary to keep track of orientation and length for each item but for the group as a whole thus allowing more opportunity to attend to color when this is required. It should be noted that the observation of rotary motion in depth does not require that observers pay attention to color which may be why there was such a poor detection of color changes under the 'blind' conditions when people were not specifically asked to respond to color. An alternative way of accounting for the effect of grouping may be that switching attention within a group is relatively fast and easy; more parallel. This may be just another way of saying that the items of the group are redundant.

Grouping is not the unitary phenomenon referred to in much of the literature. Gillam and Grant (1984) pointed out that 'aggregation' or grouping in the sense of reducing redundancy is not the same as 'unit formation' or grouping in which the parts form a new whole with emergent features. The grouping of the parallel lines in our experiment can be regarded primarily as 'aggregation' rather than 'unit formation'. In aggregation the elements do not lose their identity to participate in a new emergent figure but their similarity/redundancy with respect to certain features allows for common processing with respect to those features which is highly efficient. It is possible that if a set of lines formed a group constituting a unit with emergent features, such as closure, such grouping would retard rather than facilitate attention to and encoding of individual elements, as is found in some of the search literature. This issue requires further investigation.

The finding that the swapping of two colors was much more difficult to detect than a change of one of the colors to a new color was an even more striking finding of our experiment. This is consistent with a number of findings with other paradigms as previously discussed. Why do observers have more difficulty with swap-type changes? We suggest that the reason may be that a swap requires that observers keep track of a combination of position and color. In other words the problem lies in the general area of the difficulty of responding to conjunctions of features (Treisman & Schmidt, 1982; Treisman & Paterson, 1984; Henderson, Irvy & Prinzmetal, 1995). The 'new' condition on the other hand requires attending to and encoding color alone. It could be that introducing a new color has an attention-grabbing effect even without a transient. It perhaps changes the overall impression of 'gist' of the array. It should be noted however that even these changes were often undetected in the main experiment. This was so despite the small number of stimuli and instructions to expect changes in color. Furthermore, both kinds of change were largely undetected in the 'blind trials'. Color change does not appear to act as a very effective attention-grabber. Despite clear perception that all the lines were rotating in depth (described by participants in response to the blind trials), indicating at least some level of attention and processing of spatial features, there clearly was no representation of each line in which all its features were linked.

The present research differs from some previous research with respect to the strategies available to the observer. Rensink et al. (1997) concluded on the basis of the flicker paradigm that when searching for change, people try to encode each item separately, engaging in a somewhat serial search for the target item (the item undergoing change) making comparisons across the temporal gap. Had this been the primary strategy in the present experiments the swap in colors would have been the easier change to detect as it involved a change in two lines as compared with a change in only one in the 'new' condition[1]. However, this was not the finding. Despite the fact that twice as many lines changed color in the swap condition, it was much easier to see the change when it involved the introduction of a new color (i.e. a change to only one line as opposed to two). Thus, it seems that participants were not focusing attention on and encoding each line separately. A serial search strategy would not have been effective in our paradigm because the change did not occur at every possible opportunity (in our case movement of the lines through the median plane) as it does in the flicker paradigm.

The evidence presented here is, we believe the first to suggest that perceptual grouping influences the ability to detect changes. It was found that it is easier to detect changes in visual stimuli that are strongly grouped. It was found that when change is not expected it may not be noticed even when the stimuli undergoing change are clearly being processed with respect to other perceptual properties such as rotary motion in depth. Finally, this study provides a link between research on memory and illusory conjunctions concerning the representation of location and identity and research on change detection. It was shown that changes to location were more difficult to detect than changes to identity, defining identity as the features present rather than locations. Detecting a change in location requires keeping track of the conjunction of position and color.

These findings have some practical significance in suggesting methods of reducing change blindness in complex arrays, for example in airport flight decks where the transients of important change may not be present if the observer is not oriented to the change when it occurs. Attention to the manner in which indicators are grouped and in the kinds of color changes made may improve detectability.

[1] It is possible however that Rensink et al. (1997) might regard groups of lines rather than individual lines, as the item.

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