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Feature integration across parts in visual search

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Abstract. In the present study, participants searched for a conjunction of color and orientation either from the same part of an object (same-part display), or from different parts of an object (different-part display). While no difference was found between the two display conditions in single feature searches, conjunction search in the same-part display was significantly faster than that in the different-part display. This same-part advantage applies to both the inner part as well as the outer part of an object. These results suggest that features are more readily integrated if they are from the same part of an object than if they are from different parts of an object. The formation of object part representations thus influences how features are integrated and encoded during visual information processing.

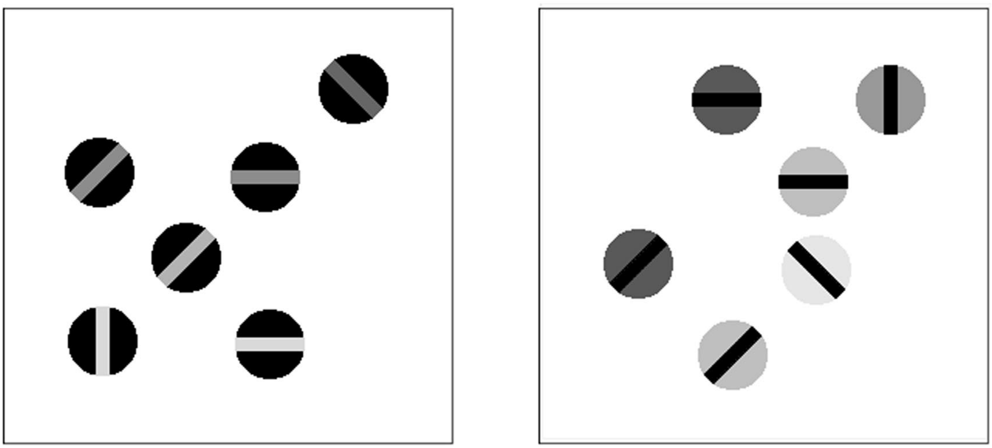
1 Feature integration across parts in visual search

A number of studies over the past three decades have shown that the processing of visual information is object-based. For example, Egly et al (1994) found that when one region of an object is attended, subsequent processing of another region of the same object is greatly facilitated (see also Moore et al 1998). Duncan (1984) found that when one feature of an object had to be reported, the report of a second feature from the same object is almost cost-free and is much better than the report of a second feature from a different object (see also Allport 1971; Irwin and Andrews 1996; Luck and Vogel 1997; Watson and Kramer 1999). In location coding, Baylis and Driver (1993) found object-based hierarchical coding of locations such that the location of a shape's concave point is encoded relative to its location on the shape, rather than its absolute location in the display. These studies suggest that features from the same object are processed together and are better integrated than features from different objects. A natural prediction from this conclusion is that features from the same object ought to be more confusable than features from different objects. Indeed, Prinzmetal (1981) found that illusory conjunction errors occur more frequently among features within the same perceptual group than between two different perceptual groups when spatial distance is equated, thus further supporting the notion of object-based feature integration (see also Prinzmetal and Millis-Wright 1984).

Most objects in our surroundings contain parts. For 3-D and 2-D shapes (silhouette) with uniform surface property, it has been shown that our visual system uses negative minima of curvature to parse shapes into parts (Hoffman and Richards 1984; Hoffman and Singh 1997; Singh et al 1999; Xu and Singh, in press; see also Baylis and Driver 1994, 1995). In many other instances, however, we encounter objects in which one object part is embedded in another object part, such as the eyes on a face and the windows on a building, etc. In these cases, our visual system uses discontinuities in surface property, such as color or texture, and figure – ground separation to locate and define parts without the need to ever compute negative minima of curvature. In the eyes on a face example, there is no negative minimum of curvature present in the front view of the eyes, and yet we see them as parts embedded in the face because the color and the texture of the eyes are different from that of a face and the outline of an eye (the figure) forms a closed boundary and separates itself from the face (the ground).

If features of the same object are processed together and better integrated than features from different objects, what would happen if an object contains parts? Will features from different parts of the same object be processed together? Or will there be a hierarchy of feature integration such that features from the same part of an object are better processed together than features from different parts of an object?

Using the change-detection paradigm (Phillips 1974), Xu (in press) studied the encoding of color and orientation in visual short-term memory (VSTM) with features either located on the same or different parts of an object as defined by figure – ground separation (one part embedded in another part). In one experiment, there were two display conditions: in condition a, participants were asked to remember the colors and orientations of the bars (figure 1a). The black semicircles were irrelevant to the task. In condition b, participants were asked to remember the orientations of the black bars and the colors of the semicircles (figure 1b). Features were found to be better registered in VSTM when they belonged to the same part of an object (condition a) than when they belonged to different parts of an object (condition b). Note that participants had to pay attention to the borders between the black and the colored areas in both display conditions to extract the relevant color and orientation information. Because the borders between the black and the colored areas were identical in the two display conditions, early feature perception was well matched. At the object level, however, the interpretations for the relevant color and orientation features were quite different: In one case the features were from the same part of an object and in the other case they were from different parts of an object. The results of Xu (in press) suggest that the formation of object part representations as defined by figure – ground separation influences how features are integrated and registered in VSTM.



(a) (b)

Figure 1. Examples of the displays used in Xu (in press). In (a), participants were asked to remember the colors and orientations of the bars, and the black semicircles were irrelevant to the task. In (b), participants were asked to remember the orientations of the black bars and the colors of the semicircles. Features were found to be better registered in VSTM when they belonged to the same part of an object, as in (a), than when they belonged to different parts of an object, as in (b).

It is unclear, however, where part-based feature integration occurs in VSTM tasks. VSTM tasks involve information encoding, maintenance, and retrieval. As such, part-based feature integration could occur in any one of these three stages. Phillips and Christie (1977) showed that information in VSTM persisted for at least 10 s if the viewer's attention was maintained (see also Phillips 1974). Recent study by Vogel et al (1998) found that after stimuli have been successfully encoded into VSTM, the presentation of a mask does not interfere with change-detection performance. These results suggest that once information is encoded into VSTM, with no distraction, information does not decay rapidly. In other words, the maintenance of information in VSTM is quite good over a period of a few seconds. If there is a limitation in participants' performance, it is most likely due to a limitation in stimulus encoding. If this is indeed the case, then we should expect part-based feature integration to occur in visual search tasks as well in which only encoding and on-line processing of visual information are required. In other words, because both VSTM and visual search tasks require the encoding of visual information, if part-based feature integration is occurring at this stage, we should expect part-based feature integration to affect the outcome of both tasks.

The goal of this study is therefore to test whether part-based feature integration occurs in visual search. To do so, the present study adapted the stimuli used in Xu (in press) to visual-conjunction-search tasks (Treisman and Gelade 1980).

2 Experiment 1A: Conjunction search

The object used in this experiment consisted of a bar embedded in a circle. During the experiment, participants searched for a red and vertical object among red and horizontal, blue and vertical, and blue and horizontal distractor objects. There were two display conditions: (i) the same-part display (figure 2a), in which the relevant color and orientation features were carried by the bar, and the color of the yellow circle was irrelevant to the search task; and (ii) the different-part display (figure 2b), in which the relevant color was carried by the circle, the relevant orientation was carried by the bar, and the yellow color of the bar was irrelevant to the search task.

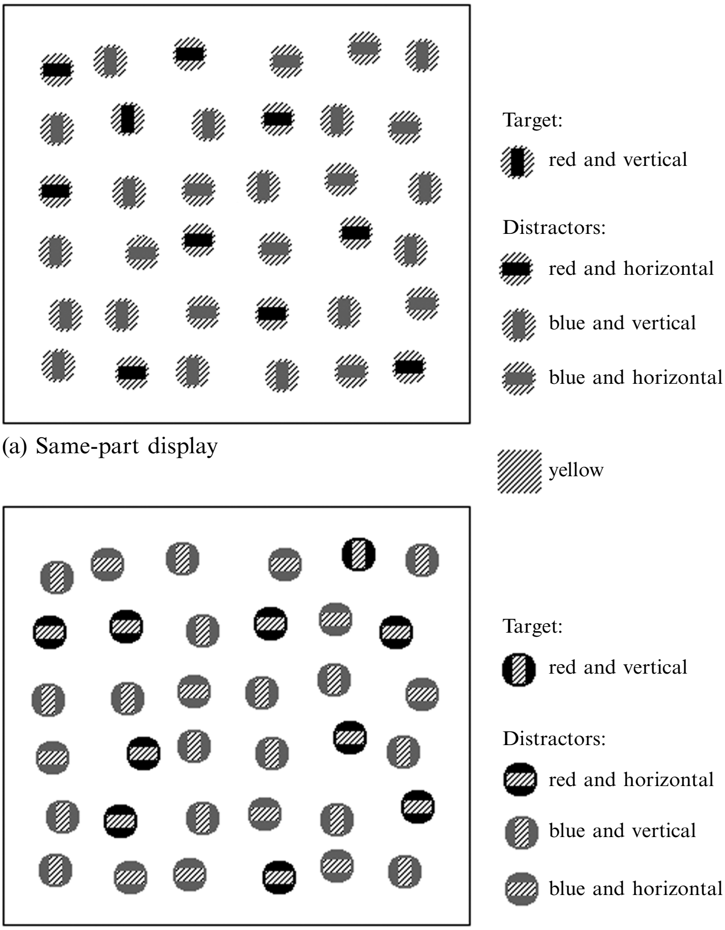
If participants were to attend to only the boundary between the bar and the circle in each object to extract the relevant color and orientation information, the perception of the relevant features from each object would be identical in the same-part and different-part conditions: no difference in search time would be expected between the two display conditions. On the other hand, if feature integration is influenced by the formation of object part representations, search would be slower in the different-part condition, which requires an integration of features across two different parts of an object, than in the same-part condition which requires an integration of features within the same part of an object.

2.1 Method

2.1.1 Participants. Sixteen volunteers, six males and ten females, from the Massachusetts Institute of Technology campus were recruited. They were between 17 and 35 years of age, all had normal color vision, and received payment for their participation.

2.1.2 Materials and design. Examples of the stimuli are shown in figure 2. The diameter of the circle was 1.03 deg and the dimensions of the bar were 0.80 deg $\times$ 0.38 deg. The dimensions of the shapes were chosen such that the area of the circle minus the bar was roughly the same as the area of the bar, so that the colored areas in the same-part and different-part objects were roughly the same. In the same-part condition, the bars were colored either red or blue and the circles were colored yellow. In the different-part condition, the bars were colored yellow and the circles were colored either red or blue.

There were 36 objects distributed in a 6×6 grid (11.4 deg $\times$ 11.4 deg) in each display. The objects were slightly offset from the grid and were never perfectly aligned with each other. Each display contained 10 red objects, all horizontal except in target-present trials in which one of them was vertical, and 26 blue objects with 16 vertical and 10 horizontal. The blue and horizontal objects were used as fillers to fill up the 6×6 matrix. Objects in a given display were all of the same object type, either same-part or different-part. The target object was always red and vertical.



(b) Different-part display

Figure 2. Examples of conjunction search displays used in experiment 1A. In (a), same-part display, the search features were on the same part of each search object—the bar; and in (b), different-part display, the search features were on different parts of each search object—orientation on the bar and color on the circle.

Participants were instructed to pay attention only to the red objects and ignore all the blue objects if possible. This was done to avoid a switch of strategy in the middle of the experiment, because some participants would eventually adopt this strategy.

The experiment contained four blocks. Each block contained a total of 64 trials, with 16 target-present trials and 16 target-absent trials for each of the two display types. Different trial types within a block were randomly intermixed. There were, therefore, in this experiment, a total of 64 target-present trials and 64 target-absent trials for each of the two display types. 16 practice trials preceded the experimental trials.

2.1.3 Apparatus. MacProbe Macintosh programming software and an iMac with a 350 MHz Power PC G3 processor and a 15-inch monitor were used to generate the displays. Reaction times (RTs) were measured by the computer.

2.1.4 Procedure. Participants were seated in a dimly lit room about 50 cm away from the computer screen. Each trial began with the presentation of a fixation dot for 505 ms, which was then replaced by the search display. The search display remained on the screen until participants pressed one of the two prespecified keys with either their thumbs or index fingers to indicate target presence/absence. The response keys were the left 'control' key and the 'enter' key on the number keypad. Key assignments were counterbalanced among participants and were marked by tags glued on top of the keys. Within a block, the next trial came automatically about $\frac{1}{2}$ s after participants responded to the previous trial. A break was given to the participants for as long as they wanted between the blocks. If a response error occurred, the computer would beep once as feedback. The experiment lasted about 10 min.

2.2 Results

2.2.1 Reaction time for correct trials.
Data were removed either because of errors (6.2%) or when RTs were longer than 3000 ms (2.6%). The remaining data were analyzed with an ANOVA and the means are shown in the left panel of figure 3a.

The effect of display type was highly significant, such that it was faster to detect the presence/absence of the target in the same-part display than it was in the different-part display ($F_{1,15} = 12.42$, $p = 0.003$). RTs were significantly faster in target-present than target-absent trials ($F_{1,15} = 83.04$, $p < 0.001$). The interaction between the two effects was not significant ($F_{1,15} = 1.09$, $p = 0.31$).

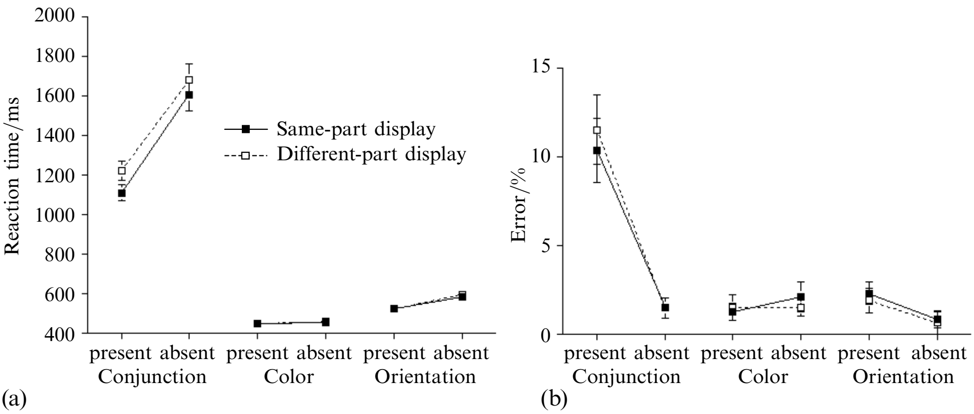


Figure 3. Results of experiments 1A and 1B: (a) reaction times for correct trials; (b) error rates. In color and orientation feature searches (middle and right plots), search time in the same-part and the different-part displays did not differ, indicating that feature perception was well matched for the two display types. In conjunction search (left plot), search was significantly faster in the same-part display than in the different-part display, suggesting that a conjunction is more readily perceived when both features belong to the same rather than different parts of the object. In all three searches, error rates did not differ between the two display types.

2.2.2 Error rates.
The mean error rate is shown in the left panel of figure 3b. There were more misses than false yeses ($F_{1,15} = 37.87$, $p < 0.001$). The effect of same versus different parts was not significant, and there was no interaction.

The results of this experiment will be discussed together with the results of experiment 1B.

3 Experiment 1B: Feature search

It is possible that the differences in search observed in experiment 1A were caused by factors other than how features are conjoined within and between parts. For example, feature integration could be quite comparable between the two display conditions, but the features in the different-part display may be harder to perceive for some reason than those in the same-part display. To determine whether the two display types—same-part or different-part—were equivalent in terms of perception of a single feature, single-feature searches were examined in experiment 1B. Only when no difference is found in feature searches between the two display conditions, would we be justified in concluding that the search differences observed in experiment 1A were due to differences in feature integration.

3.1 Method

3.1.1 Participants. Twelve new volunteers, six males and six females, from the same participant pool, were recruited.

3.1.2 Materials, design, apparatus, and procedure. The same objects as in experiment 1A were used. There were two sessions: the color search session, in which participants searched for a red object among blue objects; and the orientation search session, in which participants searched for a vertical object among horizontal objects. The presentation order of the two sessions was counterbalanced among participants.

In the color search session, conjunction displays from experiment 1A were used but with all the red distractors replaced by blue distractors of the same orientations. Each target-absent color search display thus contained a total of 20 horizontal and 16 vertical blue objects. In target-present trials, a red vertical object replaced one of the blue horizontal objects.

In the orientation search session, conjunction displays from experiment 1A were used but with all the vertical distractors replaced by horizontal distractors of the same color. Each target-absent orientation search display thus contained a total of 10 red horizontal objects and 26 blue horizontal objects. In target-present trials, a red vertical object replaced one of the red horizontal objects. Unlike in the conjunction search, participants were not instructed to search only among the red objects for the target.

In both feature searches, therefore, the target was always red and vertical as in the conjunction search; but was the only red object in the color search and the only vertical object in the orientation search. Other aspects of the experiment were identical to that of experiment 1A. The experiment (including both sessions) lasted about 10 min.

3.2 Results

3.2.1 Color search. In the analysis of RTs for correct trials, 1.6% of the data were removed owing to response errors. No RT effect reached significance, including the effect of display type ($F < 1$). Similar results were obtained in the error analysis, and again, the effect of display type was not significant ($F < 1$). These results are plotted in the middle panels of figures 3a and 3b.

3.2.2 Orientation search. In the analysis of RTs for correct trials, 1.4% of the data were removed owing to response errors. Responses for target-present trials were faster than that for target-absent trials ($F_{1,11} = 17.43$, $p = 0.002$). The effect of display type, however, was not significant ($F < 1$). In the error analysis, there were more misses than false alarms ($F_{1,11} = 9.16$, $p = 0.012$). None of the other effects reached significance. These results are plotted in the right panels of figures 3a and 3b.

In a joint analysis of the two feature searches, orientation search was significantly slower than color search ($F_{1,11} = 31.02$, $p < 0.001$).

4 Discussions of experiments 1A and 1B

The results of experiment 1B showed that in color and orientation feature searches, search time in the same-part and the different-part displays did not differ ($F < 1$), indicating that feature perception was well matched in the two display conditions. However, in the conjunction search in experiment 1A, search was significantly faster in the same-part display than it was in the different-part display, suggesting that a conjunction is more readily perceived when both features belong to the same rather than different parts of an object. These findings thus extend the results by Xu (in press) from VSTM to visual search, and suggest that the formation of object part representations influences how features are integrated during visual search.

One could argue that in the present study the same-part display looked overall homogenous with all the color circles being in the same yellow color; whereas the different-part display looked heterogeneous with some of the circles in red and the rest in blue. Although this contextual difference in color did not affect feature search for orientation (presumably because participants could ignore color while searching for orientation), it might have nonetheless slowed participants down in conjunction search and contributed to the observed differences between the two display conditions. To rule out this confound, experiment 2A used a different set of stimuli in which the same-part display looked overall heterogeneous and the different-part display looked overall homogenous. If the results of experiment 1A could be attributed to contextual differences between the two display types, then in experiment 2A we should expect an opposite pattern of results: slower search in the same-part display (heterogeneous) and faster search in the different-part display (homogenous). On the other hand, if a conjunction is more readily perceived when features belong to the same rather than different parts of an object, then search in the same-part display should still be faster than search in the different-part display with this new set of stimuli.

5 Experiment 2A: Conjunction search

In this experiment, a two-part object in which a circle was embedded in a spindle, as shown in figure 4, was used. The color feature could be carried either by the spindle or the circle; and the orientation feature was carried by the spindle. Thus, in the same-part display the relevant features were the color and orientation of the spindle; and in the different-part display the relevant features were the color of the circle and the orientation of the spindle. Note that, with this set of displays, the same-part display was more heterogeneous than the different-part display. If feature integration is easier for features from the same part than from different parts, we should still observe search to be slower in the different-part than in the same-part displays as in experiment 1A.

5.1 Method

5.1.1 Participants. Twelve participants, seven females and five males, from the Harvard University campus were recruited. They were between 17 and 35 years of age, all had normal color vision, and received payment for their participation.

5.1.2 Materials, design, apparatus, and procedure. The stimuli used are shown in figure 4. The dimensions of the spindle were 1.49 deg $\times$ 0.57 deg; and the diameter of the circle was 0.57 deg. The area of the spindle without the circle closely matched the area of the circle, and as such the color areas of the same-part and different-part objects were roughly the same. Other aspects of the experiment were identical to those of experiment 1A.

5.2 Results

5.2.1 Reaction time for correct trials. Trials with errors (5.9%) and RTs longer than 3000 ms (3.5%) were removed from the analyses. The remaining data were analyzed with an ANOVA. The means are plotted in the left panel of figure 5a.

Search was faster in the same-part display than in the different-part display ($F_{1,11} = 90.14$, $p < 0.001$), and faster in target-present than target-absent trials ($F_{1,11} = 86.44$, $p < 0.001$).

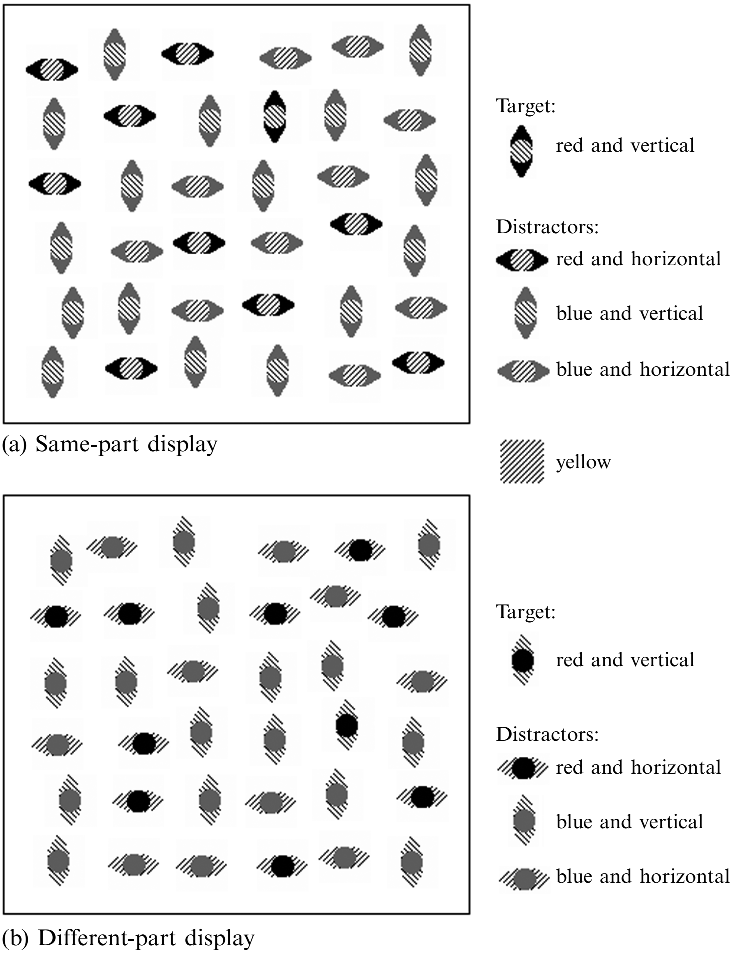


Figure 4. Examples of conjunction search displays used in experiment 2A. Feature distribution on the outer and inner shape of each object were reversed compared to that of experiment 1. In (a), same-part display, the search features were on the same part of each search object—the spindle; and in (b), different-part display, the search features were on different parts of each search object—orientation on the spindle and color on the circle.

The interaction between display type and target presence/absence was also significant ($F_{1,11} = 13.12$, $p = 0.004$), such that the differences between the two display types were bigger in the target-absent than in the target-present trials.

5.2.2 Error rates. The mean error rates are plotted in the left panel of figure 5b. Participants made more errors in the different-part than in the same-part display ($F_{1,11} = 36.21$, $p < 0.001$); more errors in the target-present than in the target-absent trials ($F_{1,11} = 74.03$, $p < 0.001$); and the two effects interacted with each other significantly with most errors occurring in the target-present trials of the different-part display ($F_{1,11} = 9.89$, $p = 0.009$). The fact that there were more errors in the different-part than in the same-part displays suggested that the differences in RTs observed in the two display types could not be attributed to a speed–accuracy trade-off.

The results of this experiment will be discussed together with the results of experiment 2B.

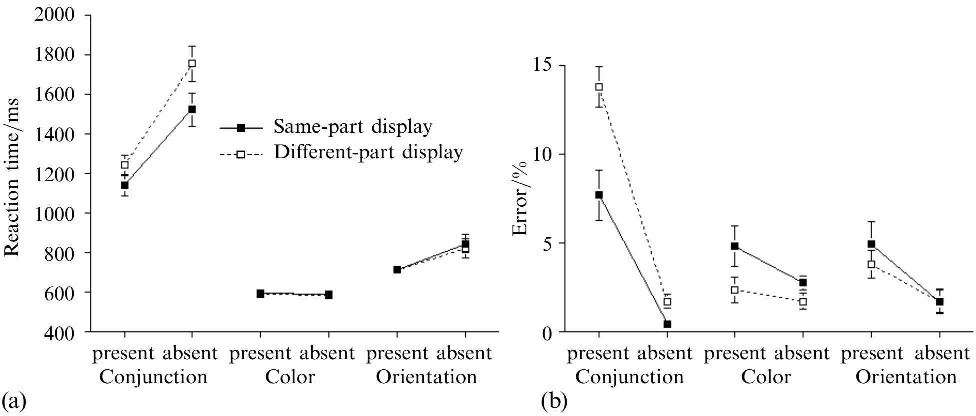


Figure 5. Results of experiments 2A and 2B: (a) reaction times for correct trials; (b) error rates. In color and orientation feature searches (middle and right plots), search time in the two display types did not differ. In conjunction search (left plot), search was significantly faster in the same-part display than in the different-part display. These results mirrored those of experiments 1A and 1B and indicated that a conjunction is most readily perceived when both features belong to the same part of the object, being either the inner or outer part of the object. Overall error rates were lower in the different-part displays in feature searches, but higher in the different-part displays in conjunction search, thus consistent with the RT results.

6 Experiment 2B: Feature search

Matched feature searches for color and for orientation were conducted in this experiment with the same group of participants who participated in experiment 2A. The feature searches were conducted before the conjunction search to avoid the possibility that participants might bias their feature searches if they had completed the conjunction search first.

6.1 Method

6.1.1 Participants. The same participants as in experiment 2A took part in this experiment before participating in experiment 2A.

6.1.2 Material, design, apparatus, and procedure. The same stimuli as in experiment 2A were used here. Feature search displays were generated according to the procedure used in experiment 1B. Other aspects of the experiment were identical to those of experiment 1B.

6.2 Results

6.2.1 Color search. In the analysis of RTs for correct trials, 2.9% of the data were removed because of response errors and 0.1% were removed when RTs were longer than 3000 ms. No RT effects reached significance, including the effect of display type ($F < 1$). In the error analysis, there were more errors in the same-part display than in the different-part display ($F_{1,11} = 20.72$, $p = 0.001$). Neither the effect of target presence/absence nor the interaction between display type and target presence/absence was significant ($F_{1,11} = 2.80$, $p = 0.12$, and $F < 1$, respectively). These results are plotted in the middle panels of figures 5a and 5b.

6.2.2 Orientation search. In the analysis of RTs for correct trials, 3.0% of the data were removed owing to response errors and 0.2% were removed when RTs were longer than 3000 ms. The effect of target presence/absence was significant ($F_{1,11} = 16.83$, $p = 0.002$), but not the effect of display type ($F_{1,11} = 2.09$, $p = 0.18$), or the interaction between these two effects ($F_{1,11} = 2.22$, $p = 0.16$). In the error analysis, the effect of display type was not significant ($F_{1,11} = 1.84$, $p = 0.20$), although there were more errors in the same-part display in the target-present trials. Overall, there were more errors in target-present trials than in target-absent trials ($F_{1,11} = 8.07$, $p = 0.016$). The interaction between display type and target presence/absence was not significant ($F < 1$). These results are plotted in the right panels of figures 5a and 5b.

Overall, as in experiment 1B, orientation search was slower than color search ($F_{1,11} = 106.10$, $p < 0.001$).

7 Discussions of experiments 2A and 2B

In experiments 2A and 2B, as in experiments 1A and 1B, the perception of single features in the same-part and in the different-part displays was well-matched: feature search (for color and for orientation separately) was equally fast in the two display conditions ($F < 1$). If anything, there were actually more errors in the same-part than in different-part displays in feature searches. Conjunction search, however, was significantly faster in the same-part display than it was in the different-part display, thus replicating the findings of experiment 1A after contextual differences between the two display types have been reversed. The average RT difference between the two display types in conjunction search in this experiment (167 ms) was certainly of the same magnitude as, if not bigger than, in experiment 1A (94 ms). In the conjunction search in this experiment, a significant interaction between display type and target presence/absence was also observed, suggesting that the effect of part-based integration is cumulative across search objects in experiment 2A. Presumably, in the target-present trials, on average, participants only had to search half the display before they would detect the presence of the target; whereas in the target-absent trials, participants had to search the entire display before they could decide that no target was present. As such, if the effect of part-based integration is cumulative across search objects, the difference between the two display types should be bigger in the target-absent than in the target-present trials. This is exactly what was found in experiment 2A.

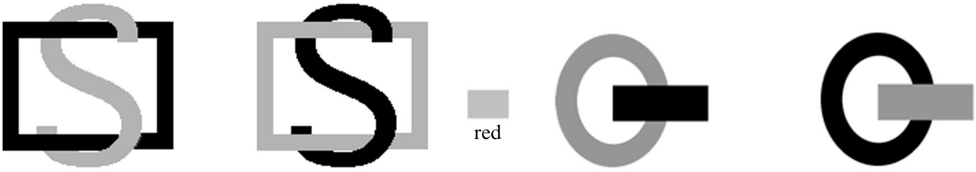
8 General discussion

In the present study, participants searched for a conjunction of features (color and orientation) either from the same part of an object (same-part displays), or from different parts of an object (different-part displays). While no search differences in RT were found between the two display types in single-feature searches, conjunction search in the same-part display was significantly faster than that in the different-part display. This same-part advantage is general in that it applies to both when the relevant search features were located in the inner part of an object (experiment 1A) and when they were located in the outer part of an object (experiment 2A). These results show that feature conjunctions are more readily perceived for features from the same part of an object than for features from different parts of an object, thus extending the results obtained by Xu (in press) in VSTM to visual searches.

VSTM tasks involve the encoding, maintenance, and retrieval of visual information, whereas visual search tasks involve only the encoding and on-line processing of visual information. The facts that both tasks involve the encoding of visual stimuli and that both tasks showed part-based feature integration suggest that part-based feature integration must occur (at least) at the encoding stage of visual information processing in general. Moreover, the fact that the same-part advantage applied to both the inner and the outer part of an object in the present study suggests that the same-part advantage is not modulated by the spatial location of a part within an object. Feature integration across parts is always harder than feature integration within the same part of an object.

One may argue that feature search performance is generally not affected much by discriminability of the relevant feature, except when discriminability is very low; whereas performance in conjunction search may vary greatly, depending on the discriminability of the relevant features (eg Wolfe et al 1989). As such, null results from feature searches do not rule out the possibility that the effect in conjunction search could be due to differences in feature discriminability. In experiment 2B, although there were no RT differences between the same-part and different-part displays in feature searches, there were actually more errors in the same-part display than in the different-part display. This difference reached significance in color search. If anything, this result indicates that color was slightly harder to perceive in the same-part display than in the different-part display. And yet, despite the advantage in feature perception in the different-part display, conjunction search in the same-part display was still significantly faster than that in the different-part display. It is therefore reasonably safe to conclude that the differences observed in conjunction search between the two display types were caused by how features are conjoined in these displays.

Similar results that conjunction search for features located in the same part of an object is faster than that for features located in different parts of an object have also been obtained by Goldsmith (1998), whose stimulus consisted of spatially overlapping shapes. Goldsmith found that conjunction search for red and S was faster for stimulus that consisted of a red S and a black box (figure 6a) than for stimulus that consisted of a black S and a red box (figure 6b). Unlike the present experiment, however, Goldsmith did not test whether the two display conditions were matched in early feature perception. Moreover, given that the two shapes (S and box) used in Goldsmith's study did not completely overlap with each other, in the same-part condition it would have been possible for participants to attend only to the center of each stimulus and look for the presence/absence of a red curve which indicates the presence of the target red S and completely ignores the square in the surround; whereas in the different-part condition participants needed to attend to the two shapes in different spatial locations before they could integrate the features. As a result, the spread of attention and how big an area was attended, rather than part-based integration per se, might have generated the results obtained by Goldsmith. The present study used objects in which one object part was embedded in another object part. In order to extract the relevant search features, participants had to attend to the entire object in both types of displays, especially in experiment 2A when the orientation feature was carried by the outer shape. As such, the spread of attention and how big an area was attended were well matched in the same-part and different-part displays in the present experiments. The design and the manipulations of this study therefore made the present findings much stronger than those of Goldsmith.



(a) (b) (c) (d)

Figure 6. (a) and (b) Examples of target stimuli adapted from Goldsmith (1998). In (a), the relevant search features (red and S) were located on the same shape; whereas in (b) the relevant search features were located on two spatially overlapping shapes. (c) and (d) Examples of target stimuli adapted from Wolfe et al (1990, their experiment 6). In (c), the relevant search features (red and C) were located on the same shape; whereas in (d), the search features were located on different shapes.

Wolfe et al (1990, his experiment 6) also conducted a conjunction search study in which the relevant color and shape features were either located in the same spatial location (same part of an object, figure 6c) or in different spatial locations (different parts of an object, figure 6d). From the fact that no differences in search slopes between these two conditions were found, Wolfe et al concluded that for a color × shape conjunction search, search is equally efficient regardless of whether the features are located in the same spatial location (same part) or different spatial locations (different parts). A close examination of the results, however, revealed that search time in the different-location (different-part) condition was longer, especially in displays with larger set sizes, than that in the same-location (same-part) condition. As Goldsmith (1998), Wolfe et al did not test whether the two display conditions were matched in early feature perception as was done in the present study. As such, although the differences in RT in Wolfe et al could have resulted from factors other than how features were conjoined, the results of Wolfe et al, nonetheless, are not contradicting, if not in agreement with, the present findings.

In both experiments of the present study, one object part was embedded in another object part and defined/located through color discontinuities and figure – ground separation. This method of defining/locating object parts has certain degrees of ambiguity: Owing to the lack of depth information, both occlusions and embedded object parts may give rise to the same perceptual experience. As such, one may argue that the two-part objects used in the present study actually consisted of two objects with the smaller object lying on top of, rather than embedded in, the larger one.

Note, however, that in the present experiments, the two shapes of each object (a circle and a bar/spindle) were always presented in the same configuration/alignment through out the display. According to the generic view principle (Rock 1983) and Gestalt grouping principles the probability of each circle-bar/spindle pair being a single object with two parts would be much greater than the probability of each circle-bar/spindle pair being two independent objects with one lying on top of the other, only accidentally in perfect juxtaposition. In other words, because the circle and the bar/spindle of each object were always presented in a fixed relationship, they were no longer independent of each other, and therefore, should not be considered as two independent objects. Try as one may, the fact that these two shapes were parts of a larger object is undeniable.

Although the generic view principle and the Gestalt grouping principles do not define objecthood, they do dictate to a great extent how we perceive and interpret the visual world. The most striking illustration of the Gestalt grouping principle comes from research on neglect and Balint's patients: when elements were grouped together according to Gestalt principles to form a single perceptual group, patients' perception of these elements improved greatly (eg Behrmann and Tipper 1994; Humphreys and Riddoch 1993; Mattingley et al 1997; and many others). Illustrations of the generic view principle may be found in Palmer (1999).

In summary, the present study shows that, in visual search, features are more readily integrated if they are from the same part of an object than if they are from different parts of an object. The formation of object part representations thus influences how features are integrated and encoded during visual information processing.

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