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Research Note

"Effortless" Texture Segmentation and "Parallel" Visual Search are *not* the Same Thing

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If a region composed of one set of texture elements is effortlessly perceived on a background composed of another set, the texture segmentation is said to occur "preattentively". If the time required to find a target item among distractor items is independent of the number of distractor items, the visual search is said to occur with all items processed "in parallel". Effortless, preattentive texture segmentation and parallel visual search are sometimes assumed to be equivalent measures of the same parallel processing stage in the visual system. The demonstrations presented here show that this is not the case. Parallel processing can occur with stimuli that do not support effortless texture segmentation and vice versa.

Texture segmentation   Visual search   Preattentive vision

Two abutting textures may form an immediately perceptible border. Alternatively, it may require scrutiny of the elements composing the two textures to determine where one texture ends and the other begins. In the former case, texture segmentation is often said to occur "preattentively" (Julesz, 1981). In a visual search task, subjects search for a target item among a number of distracting items. If the time required to complete the search is roughly independent of the number of distracting items (the set size), the search is thought to proceed with all items processed in parallel (Treisman & Gelade, 1980). It is often assumed, implied, or asserted that effortless texture segmentation and parallel visual search are two measures of the same underlying, preattentive processing (see Julesz, 1984; Rubenstein & Sagi, 1990; Treisman, 1985, 1986 for a by no means comprehensive sample).

The purpose of this brief communication is to demonstrate that texture segmentation and parallel visual search, while no doubt related, are not interchangeable measures of preattentive processing. Texture segmentation and visual search each require two sets of stimuli; call them *figure* and *ground* for texture and *targets* and *distractors* for search. For any such stimuli, there is a two by two set of possible relations between texture segmentation and visual search. The stimuli either support effortless segmentation or they do not. The stimuli either support parallel search or they do not. If segmentation and search were interchangeable, only two of the four possible cells would be filled in this two by two array. If stimuli supported segmentation, they would support parallel search. If they did not support segmentation, they would not support search. However, as the four primary figures show, examples can be found to fill all four cells.

At the top of each figure is a texture. At the bottom is a plot of the results from a *visual search* task using the same stimuli. The visual search results are average data from 10 subjects. Each subject was tested for 330 trials with the first 30 discarded as practice. All search experiments are drawn from previously published or current work in my laboratory. Details of experimental methods can be found in the cited publications. These illustrations are demonstrations and not experimental proof. For that we would need to carry out something like detection experiments with the textures, something that has not been done for this brief note.

Figure 1 gives an example of effortless segmentation with parallel search. As has been demonstrated innumerable times, a region of one orientation is readily segmented from a homogeneous region of another orientation. Similarly, search is easy and independent of set size for a target of one orientation presented amongst distractors of another orientation (data from Wolfe & Cave, 1989).

Figure 2 shows the opposite case: no segmentation and apparently serial, self-terminating search. Here the target/figure is the letter "T" and the background/distractors are "L"s. The Ts and Ls are allowed to assume any of four, 90 deg rotations. While the Ts are easy enough to find in the texture, they do not support a texture boundary. In the search task, the individual Ts and Ls are easily discriminable. The reaction times (RTs)

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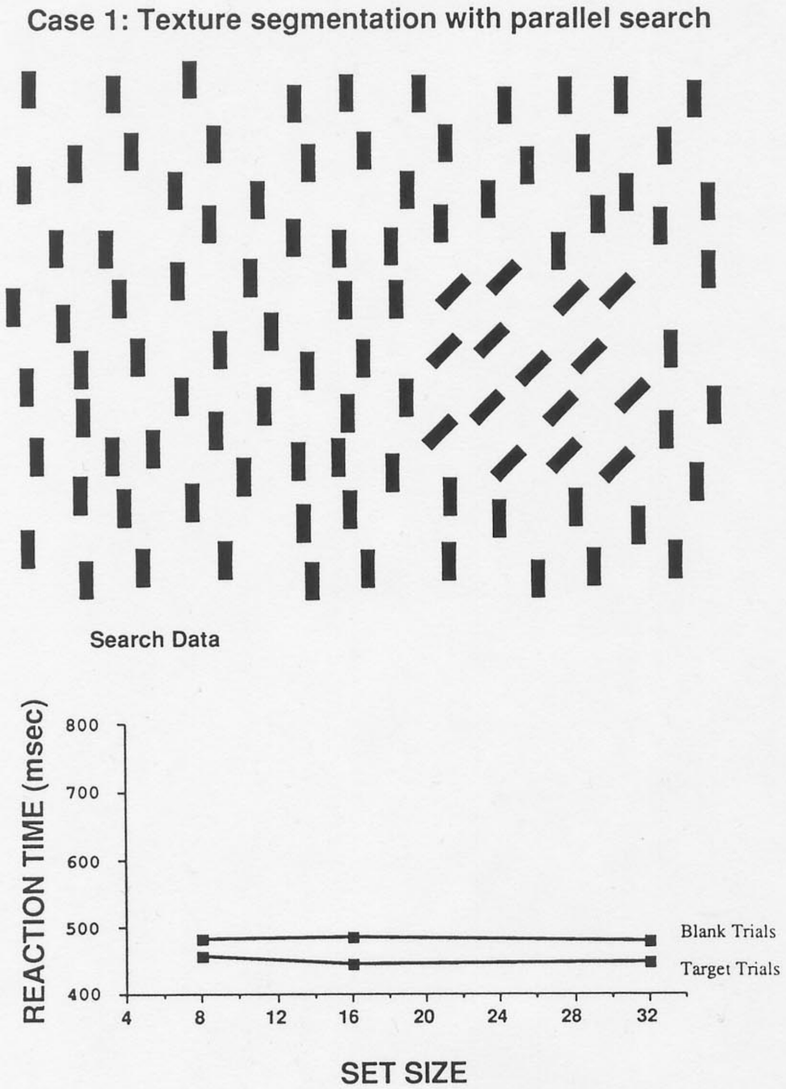

FIGURE 1. Effortless texture segmentation and parallel visual search. Oblique lines among verticals can form a preattentively visible texture and will support visual search with RTs independent of set size.

for a set size of one are comparable to RTs from the orientation search in Fig. 1. However, RT increases linearly with set size and slopes of the RT × set size function are twice as great for blank trials as for target trials as predicted by a serial, self-terminating search (data from Wolfe, Cave & Franzel, 1989).*

Figures 1 and 2 represent the cases consistent with the hypothesis that search and segmentation are equivalent measures of preattentive processing. Figures 3 and 5 illustrate the exceptions. In the texture in Fig. 3, the background is composed of black horizontal and white vertical items. The figure is composed of black vertical and white horizontal items. The figure is distinguished from the ground on the basis of a conjunction of color and orientation. No segmentation is seen. The search experiment, drawn from Yu and Wolfe (1992), uses red and green rather than black and white but this difference is not important. For the target trials of the search task, RTs are virtually independent of set size. Apparently, the target can be found in parallel. If no target is present, some subjects may fall back upon a serial search to assure themselves of its absence. This produces the fairly steep slope for the blank trials. The important point is that conjunctive stimuli of this sort can support a search that is independent of set size but do not support effortless texture segmentation.

It used to be thought that conjunctions required serial search (Treisman & Gelade, 1980) but a substantial body of more recent data shows that this need not be the case (Dehaene, 1989; Egeth, Virzi & Garbart, 1984; Nakayama & Silverman, 1986; Quinlan & Humphreys, 1987; Treisman & Sato, 1990; Wolfe *et al.*, 1989). With the exception of Nakayama and Silverman, these tasks have involved a single conjunctive target. Here we use two targets because its simplifies the construction of the texture. If a single target item were used, then the figure

*It should be remembered that linear slopes and 2:1 slope ratios are not by themselves definitive proof of serial self-terminating search (Townsend, 1971). The thrust of this paper remains the same if "parallel" searches are simply considered to be much more efficient than "serial" searches. It is worth noting that, in the case of this T vs L search, recent evidence from several paradigms support the contention that this is a serial search (Kwak, Dagenbach & Egeth, 1991).

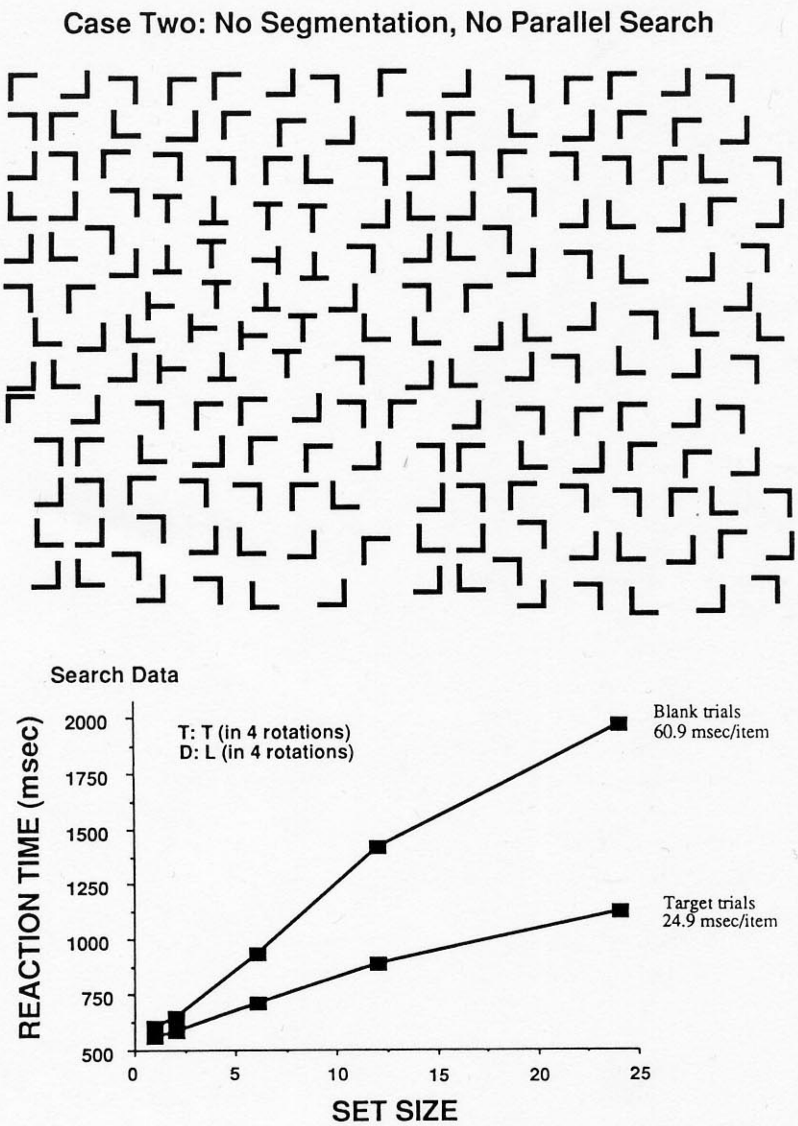

FIGURE 2. No texture segmentation and serial visual search. "T"s among "L"s do not show segmentation and produce the steep slopes and 2:1 blank to target trial slope ratios characteristic of serial, self-terminating search.

in the texture would be all of a single color and a single orientation (e.g. black vertical) while the background would be a mix of two colors and two orientations. The resulting texture segmentation could be based on a simple feature difference between figure and background as in Fig. 1. Use of two target items eliminates this problem.

Unfortunately, the use of two targets introduces a different problem. In the search task, subjects must find *either* one or the other target type. In the texture, the target patch is composed of *both* types of target. Using Fig. 4 we can show that the failure to segment the texture in Fig. 3 is related to the conjunctive status of the items. In Fig. 4, all the white verticals in the background are rotated to horizontal. The black verticals in the figure now "pop-out". Of course, the white horizontals do not since they are now the same as half of the background elements. Thus, in Fig. 3, some texture segmentation should have been possible even if only one of the two target types "popped out". In fact, if you return to Fig. 3 and look specifically for black verticals, you may get some weak segregation. The important point is that this segregation is stimulus-driven, automatic or "effortless" in Fig. 4 but not in Fig. 3. Any segmentation in Fig. 3 requires top-down knowledge of the items in the figure region.

In Fig. 5, stimuli are again conjunctions. However, these are conjunctions between two orientations rather than between an orientation and a color. The target/figure is vertical and oblique while the background/distractors are vertical-horizontal and oblique-horizontal items. Luminance polarity is varied to minimize use of the overall shape of each item as a cue. Texture segmentation is quite easy while search is quite slow and apparently serial. The search data are drawn from Wolfe, Yu, Stewart, Shorter, Friedman-Hill and Cave (1990), a paper that illustrates that searches for color × color and orientation × orientation conjunctions are invariably serial. Figure 5 demonstrates that segmentation is possible even if parallel search is not.

It is actually trivial to generate a host of examples of this sort. Consider the case where the target is a line

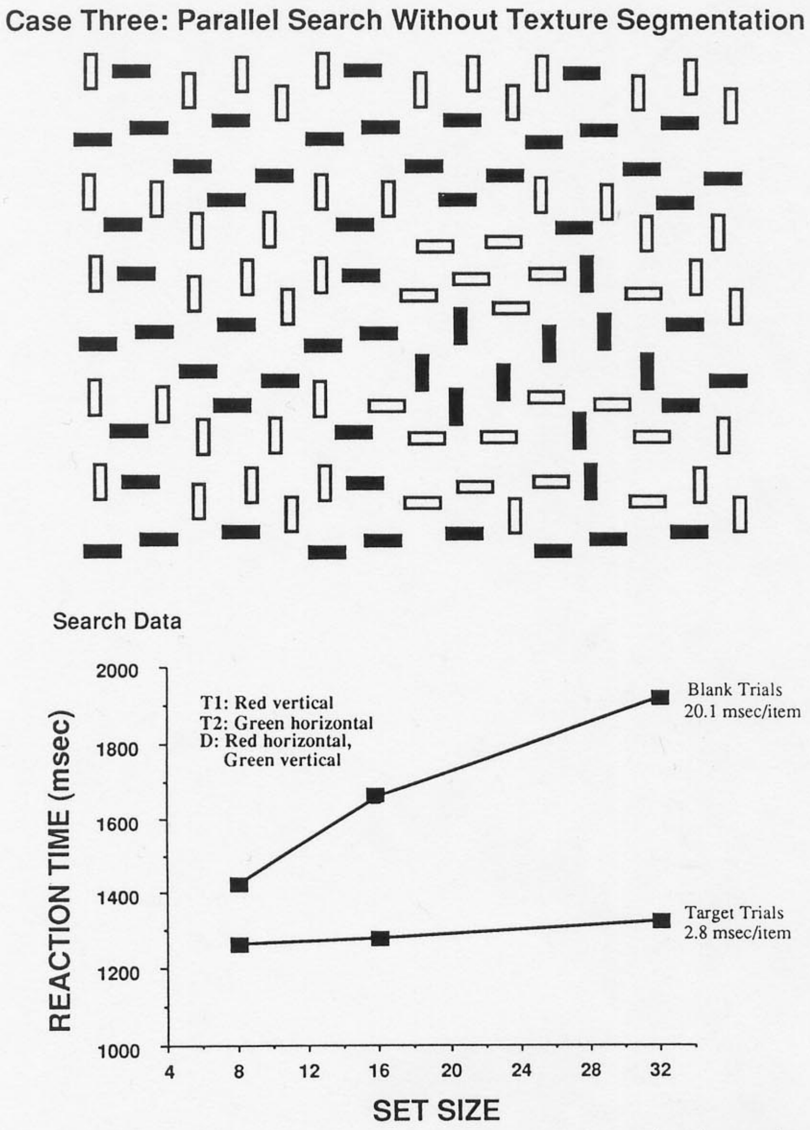

FIGURE 3. Parallel visual search without texture segmentation. Color × orientation conjunctions produce visual search RTs that are virtually independent of set size but the same stimuli fail to produce texture segmentation.

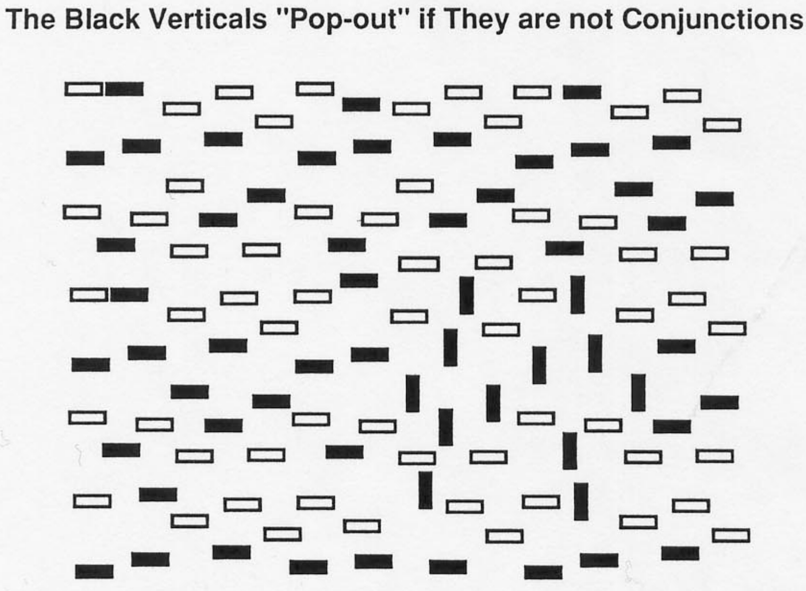

FIGURE 4. The texture is the same as that in Fig. 3 but with the white vertical items rotated to horizontal. The black verticals now segment effortlessly.

tilted 20 deg to the right of vertical. The distractors are 40, 60, and 80 deg to the right, 20, 40, 60, and 80 deg to the left and vertical. This is a very difficult, apparently serial search task (Wolfe, Friedman-Hill, Stewart & O'Connell, 1992; see also Moraglia, 1989). However, if one imagines a homogeneous figure composed of 20 deg lines placed on a background composed of the distractor orientations, it is clear that texture segmentation would be easy. This may be considered to be a degenerate case. The field would be segmented into regions of homogeneous and heterogeneous orientation. Figure 6 shows a more instructive case. Here the figure is composed of lines 70 deg to the left and 20 deg to the right of vertical. The background is composed of lines 30 deg to the left and 60 deg to the right of vertical. The figure is easily seen though homogeneity is the same in figure and ground. Though we have not used these specific orientations in a search task, other results make it obvious that this would be a very difficult search. The ease of texture segmentation seems to be based on a global property, perhaps average orientation, that aids segmentation but is not available for search.

Segmentation in Fig. 5 probably relies on a global property as well. Passing this image through standard early vision filters (e.g. Bergen & Adelson, 1988; Gurnsey & Browse, 1989; Malik & Perona, 1990; Rubenstein & Sagi, 1990), would probably reveal more vertical and oblique energy in the figure than in the ground. The greater density of vernier offsets in the figure might also be a cue (Fahle, 1991).

The preceding figures illustrate that there are examples to fill all four cells in the two by two array of possible relations of segmentation and search. However, it should not be concluded that segmentation and search are uncorrelated. In general, stimuli that support segmentation will support parallel search and vice versa. This is only reasonable. Both processes are receiving their input from the same set of channels in early vision (Sutter, Beck & Graham, 1989). Nevertheless, it should be remembered that search and segmentation are different tasks. To borrow a useful distinction from Adelson and

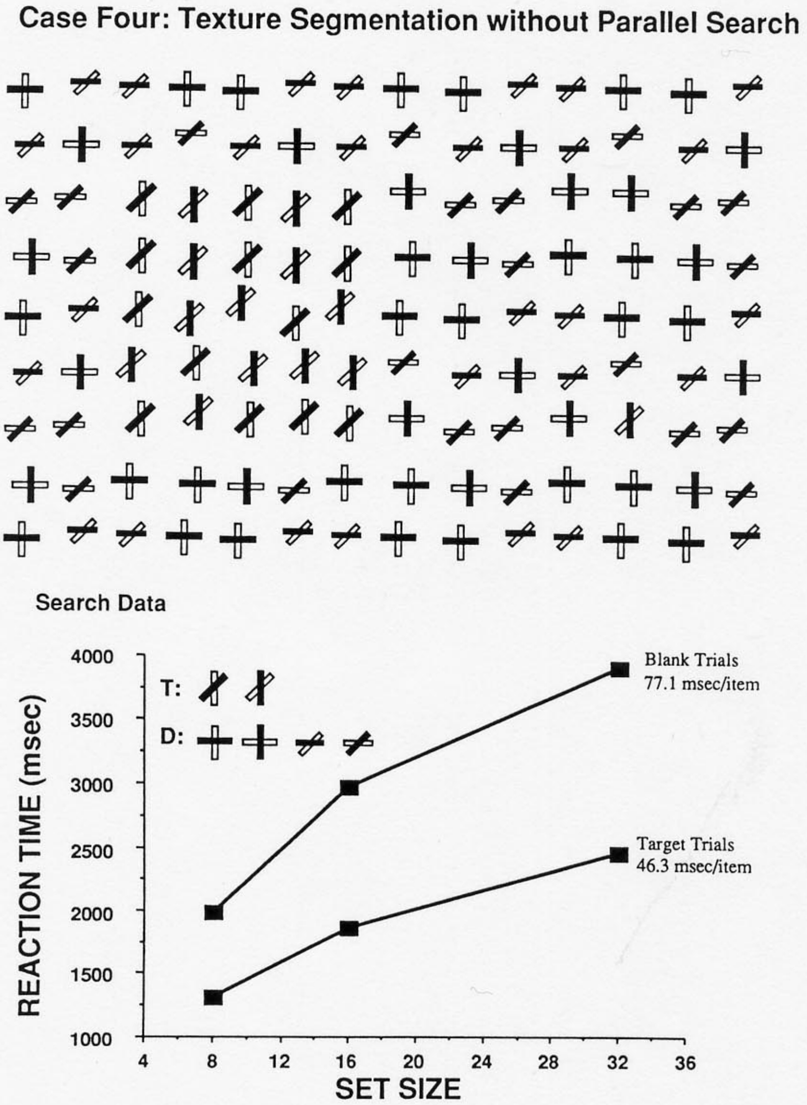

FIGURE 5. Effortless texture segmentation without parallel visual search. Orientation × orientation conjunctions produce visual search RTs consistent with serial self-terminating search. The same stimuli will produce effortless texture segmentation.

Texture segmentation from differences in average orientation

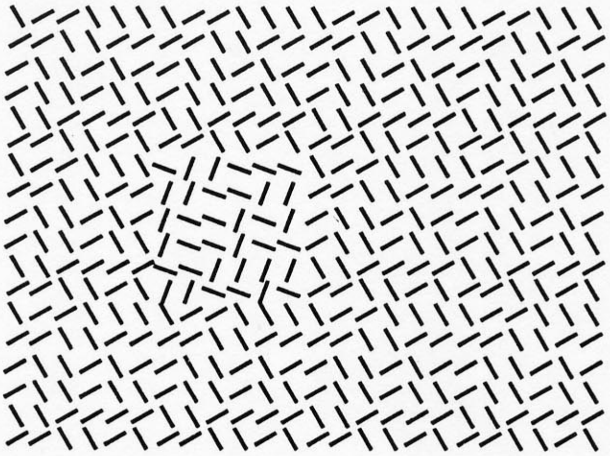

FIGURE 6. Effortless texture segmentation without parallel visual search: a second example. Figure and ground are each composed of lines of two orientations separated by 90 deg.

Bergen (1991), texture segmentation is segmentation of one kind of "stuff" from another while search is the search for some "thing". Textures can be continuous. Search is a search over a set of items.

Figures 3 and 5 point to important distinctions between the capabilities of the search and segmentation processes. Consider Fig. 3. Targets defined as color × orientation conjunctions can be found quite efficiently in visual search (as can targets defined by most other conjunctions between basic features). We have proposed that this is accomplished by a search mechanism that can use preattentive information to *guide* subsequent, attentional processing (Cave & Wolfe, 1990; Wolfe *et al.*, 1989). Thus, in a search for a red vertical item, the search mechanism can *ask* the parallel color processor to activate all red items and ask the orientation processor to activate all vertical items. Summing those activations would cause red vertical items to have the greatest activation but degradation by internal noise makes this process imperfect (Cave & Wolfe, 1990). In a search for a red vertical item OR a green horizontal as in Fig. 3, our data suggest that subjects execute a pair of these guided searches, first for one target type and then, if needed, for the other (Yu & Wolfe, 1992). Apparently, the texture segmentation mechanisms do not have this ability.

More generally, there appear to be two aspects to parallel processing in visual search: a bottom-up, stimulus-driven aspect and a top-down, cognitively- or strategically-driven aspect. The bottom-up component directs attention to unusual loci including isolated, unique items and borders. We may conjecture that this component is responsible for the subjective experience of "pop-out" and may be similar or identical to the preattentive texture segmentation mechanism. The top-down component allows for parallel selection of all items with a given attribute ("red," "steep," etc.) It allows for goal-directed use of preattentively processed information. For example, it can be used to find red M&Ms in parallel even though they are randomly placed and no more unusual than any other color (Duncan, 1989; Wolfe *et al.*, 1989). The top-down component does not seem to yield the experience of "pop-out".

Turning to Fig. 5, segmentation without parallel search seems to occur when multiple items create a cue unavailable in a single item. Guided search is not possible for an item defined by a conjunction of two orientations, apparently because the search mechanism's top-down activation of "vertical" and "oblique" yields roughly equal activation of all items (Yu & Wolfe, 1992). However, a region of vertical–oblique items has an overall order and orientation different from a region containing horizontal–oblique and horizontal–vertical items. As the region shrinks, this global cue is reduced and, in the limit with a region of one item, the task reverts to a serial search. In fact, close examination will show that Fig. 5 contains a single isolated vertical-oblique item some distance from the larger vertical–oblique region. It does not "pop-out".

In sum, texture segmentation and parallel visual search are not two measures of a single underlying mechanism. If stimuli support both segmentation and search, it seems reasonable to conclude that preattentive processing provides all the necessary information to both processes. However, integration of information across multiple items may produce effortless texture segmentation with stimuli that cannot support parallel search while top-down control of parallel processing may yield guided or even parallel search with stimuli that cannot support texture segmentation.

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