The influence of segmentation and uncertainty on target selection

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This study examines how two factors affect target selection: the contiguity of the target with the surrounding surface and certainty about target location. Previous studies indicate that a target among distractors is easier to find when the search items are on the same surface rather than different surfaces. In contrast, our recent study indicates that when the target is in a known location, sensitivity to the target is higher when it is clearly separated from the surrounding surface. Here we examine the effects of both surface contiguity and uncertainty about target location on contrast discrimination. Observers were asked to detect a contrast change on a grating target that was either segmented or contiguous with the surround grating and occurred either at a known or unknown location. Thresholds for contrast discrimination depended critically on both segmentation and location uncertainty. When the contrast change appeared at a known location isolated from the background, segmentation aided the selection of the target location, but when the contrast change occurred at an unknown location on a contiguous background, grouping of the surface as a single entity aided the detection of the target location as a discontinuity from the surface.

Introduction

How does attention select a target on a textured background? Previous studies indicate that regions are grouped into surfaces and that attention spreads across such a surface (Driver, Davis, Russell, Turatto, & Freeman, 2001; Duncan, 1984; He & Nakayama, 1995; Valdes-Sosa, Cobo, & Pinilla, 2000). He and Nakayama (1995) have shown the importance of surface layout in visual perception: It is easier to find a target among distractors when these items occur on a common surface than when they occur on different surfaces. Thus, one would expect that it is easier to find a target on a textured background that is seen as a single surface.

Our recent study on the effect of texture segmentation on target selection (Kim & Verghese, 2012) appears to contradict the single-surface advantage for targets. Observers were asked to discriminate the contrast of a target at the center of a textured region, both when the center was segmented from the rest of the texture and when it was contiguous. To achieve the same level of performance, contrast changes had to be *higher* in the unsegmented condition, indicating that discriminating contrast change on a uniform surface is more difficult than on a part of the surface that is clearly isolated. One explanation is that the segmented surface reduced spatial uncertainty of the target compared to the unsegmented surface. The contrast change always occurred at the center, but in the unsegmented condition, the center region was not clearly demarcated. Another possibility is that the contrast discrimination process is different when the increment occurs on an isolated region and when it occurs on part of a continuous surface. In the latter case, contrast discrimination may be achieved by monitoring deviations from a uniform texture. If this is true, then uncertainty in target position should have little effect on discrimination thresholds in the unsegmented case whereas location uncertainty should have a more typical effect when the potential target locations are isolated (J. Palmer, Verghese, & Pavel, 2000).

Our approach is simple: to compare contrast discrimination on clearly segmented and unsegmented surfaces and to determine whether target uncertainty is the explanation for the difference in performance. Although the effects of both uncertainty and texture grouping on target detection have been studied extensively with a wide variety of stimuli, configura-

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tions, and methods, these two factors have been typically examined in separate experiments using different methods (Akyürek, Dinkelbach, Schubö, & Müller, 2010; Cohn & Lasley, 1974; Davis, Kramer, & Graham, 1983; Duncan & Humphreys, 1989; Foley & Schwarz, 1998; Laarni, Näsänen, Rovamo, & Saarinen, 1996; Meinecke & Donk, 2002; J. Palmer, Ames, & Lindsey, 1993; J. Palmer et al., 2000; Schubö, Wykowska, & Müller, 2007). In this study, we systematically examine the effects of both uncertainty and texture segmentation on the observer's contrast-discrimination (target-detection) performance. Our goal is to determine how the interplay between position uncertainty and texture segmentation affects sensitivity to the target.

Method

Observers

A total of five observers (three women and two men) participated in each of the two experiments in this study. The first experiment measured contrast discrimination at a fixed location on segmented and unsegmented surfaces, and the second experiment measured the effect of location uncertainty on contrast discrimination in these two surfaces. All observers had normal or corrected-to-normal visual acuity, gave informed consent to participate as paid volunteers, and were tested individually in a dark room. The Institutional Review Board of Smith-Kettlewell Eye Research Institute approved the study.

Stimuli

Targets and backgrounds were circular sinusoidal gratings in both Experiments 1 and 2. All visual stimuli were displayed on a 22-in. CRT (LaCie Electron Blue IV) monitor set to a 100-Hz refresh rate. Luminance calibrations were performed using a Spyder 3 Express, and monitor gamma tables were adjusted to ensure response linearity and a constant mean luminance of 52 cd/m^2. The target and surround were composed of vertical gratings with a spatial frequency of 3 c/°. The surround grating was either contiguous with or segmented from the center target by a small gap (Figure 1a). The target radius was 0.3°. In the segmented condition, the gap size and inner radius of the segmented surround were 0.25° and 0.55°, respectively. The outer radius of the surround texture was 2.5°.

The textured gratings were presented on both sides of fixation at an eccentricity of 4.74° (1.5° below and 4.5° to the left/right of fixation). We replicated the surround texture characteristics in Kim and Verghese (2012) and set the surround gratings on the left and right to flicker on and off at 16.67 and 12.5 Hz, respectively. The left and right texture gratings were set at 40% and 36% contrast, respectively, so that they appeared perceptually matched with each other. A valid cue indicated the side on which the target grating would appear. When the target appeared briefly for 0.48 s, it also flickered at the same frequency as the textured background on the cued side. The contrast modulation was windowed by a circular profile in space and by a square wave in time, similar to the onset-offset of the large flickering surround.

Experimental procedure

The observer initiated each trial with a button press (Figure 1c). A central arrow cue then appeared to direct the observer's attention to the target on the left or the right. The cue indicated (with 100% validity) the side on which a contrast change would appear on the target grating. During the subsequent 2.4-s period, the observer voluntarily attended to the cued grating to perform contrast discrimination on it while maintaining fixation at the central cue and attempting to withhold eye blinks. In Experiments 1 and 2, a contrast change briefly appeared for 480 ms on the flickering textured background grating at a random time (0.96 s or 1.44 s) after the start of the trial. The contrast change either decreased or increased the target contrast relative to the contrast of the surround grating. At the end of a trial, the observer indicated the sign of the contrast change by pressing one of the two keys on the keyboard.

Contrast discrimination was measured in separate blocks on segmented (Experiment 1A) and unsegmented textures (Experiment 1B), using four levels of contrast with respect to the mean contrast. In Experiment 1, the contrast change occurred at a known location, at the center of the texture grating. Each observer ran a total of 128 trials in two blocks of 64 trials each for the two segmentation conditions. We gave observers breaks within and between blocks as necessary. The values of the contrast change were set to −22%, −15%, 12%, and 20% contrast for the segmented and unsegmented conditions. For two observers (O1 and O3), the deviations of the target contrast from the background had to be increased to −30%, −22%, 17%, and 25% for the unsegmented condition.

Experiment 2 was similar to Experiment 1 except that the contrast change could occur in one of three locations. The possible target locations were 0°, 1.2°, and 2.3° from the center of the texture along an imaginary line connecting the center of the texture to

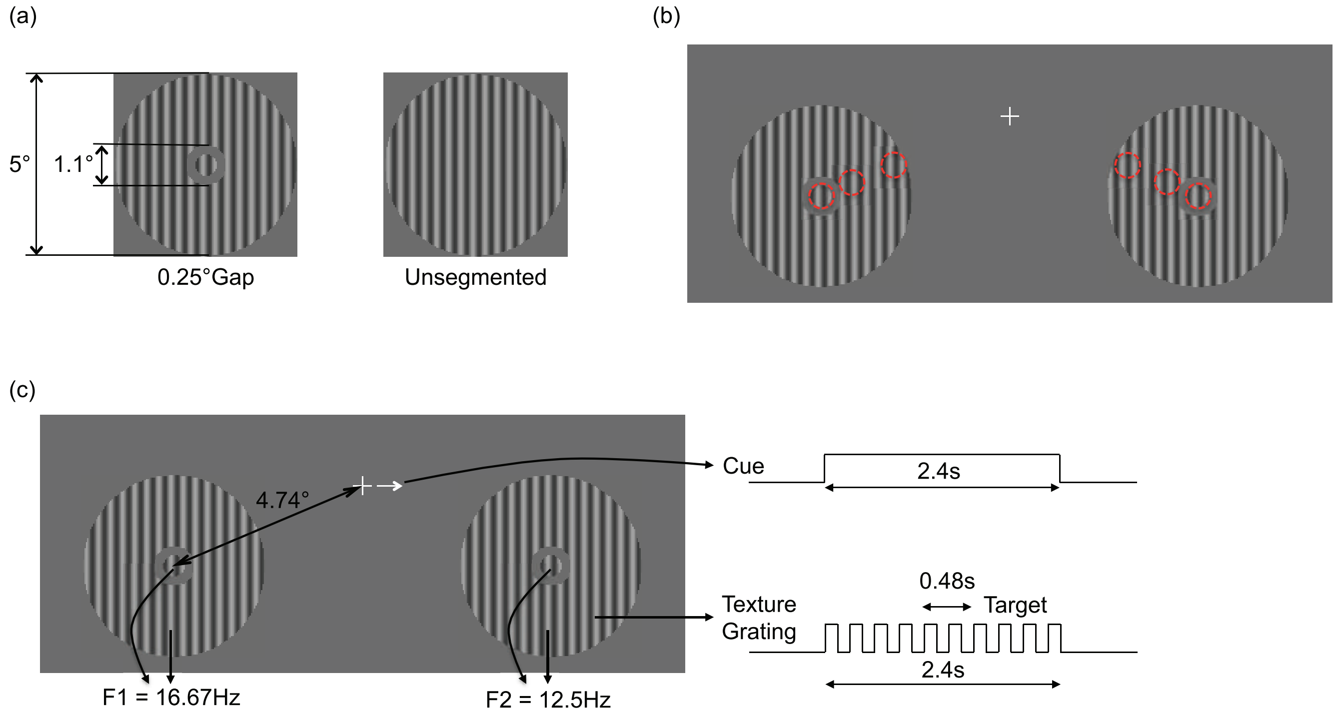

Figure 1. Stimuli and trial sequence. (a) Segmented and unsegmented texture conditions. The diameter of the center grating was 0.6° (0.25° gap) in the segmented condition. (b) In Experiment 1, the target always appeared at a fixed location at the center of the larger surround grating. In Experiment 2, the target occurred at one of three possible locations indicated by schematic red circles. These locations were 0°, 1.2°, and 2.3° from the center of the texture and were located along an imaginary line connecting the center of the texture to the fixation point. (c) In each trial, two background gratings were simultaneously presented, centered 4.5° to the left and right of fixation and 1.5° below it. The textures (center + surround) flickered at 16.67 Hz on the left and at 12.5 Hz on the right. The trial lasted 2.4 s and started with the appearance of the cue at the fixation point indicating the location (left or right) of the increment. The contrast change briefly appeared for 480 ms on the flickering textured background grating at a random time (0.96 s or 1.44 s) after the start of the trial. See Movie 1 for a short video demonstration of the trial sequence in the segmented condition.

the fixation point (Figure 1b). From trial to trial, the observer did not know which of the three locations would have the target and therefore had to attend to all locations to the best of his or her ability. Because we were interested in studying the effect of uncertainty on segmentation, we kept the surround configuration identical to that used in Experiment 1. Only the target location at the center of the grating texture was separated by a gap in the segmented conditions; the other two locations were contiguous with the surround grating in both the segmented and unsegmented conditions. (We also ran a control experiment in which all three locations were segmented. These data are presented in Supplementary Materials.) The segmented and unsegmented conditions were run in separate blocks. For each background condition, we tested observers for a total of 384 trials in four blocks of 96 trials each. We gave observers breaks within and between blocks as necessary. The values of the contrast change on the two backgrounds were –30%, –20%, 16%, and 23%.

Monitoring eye movements

As the stimuli are presented eccentrically and the display duration is long (2.4 s), it is important to monitor eye position and ensure that observers are fixating the central cross and not looking directly at the peripheral stimuli. We used a ViewPoint Eye Tracker (Arrington Research) sampling at 224 Hz to monitor eye position of the left eye while the observer performed a contrast-discrimination task in Experiments 1 and 2. Viewing was binocular. Head position was maintained with chin and forehead rests. Calibration was performed in two stages. Each block of trials started with the eye tracker's default calibration program that used a 4 × 4 grid that spanned the display, which was then followed with a custom calibration using a 5 × 5 point grid that spanned the central 10° of the display where our stimuli were presented.

Trials that contained any large eye movements (>1°) were excluded for further statistical analysis of behavioral data. On average, observers maintained fixation (within a 1° window around the fixation cross)

	Fixed segmented	Fixed unsegmented	Uncertain segmented	Uncertain unsegmented
O1	0%	1.56%	0.52%	0.26%
O2	13.28%	3.91%	8.33%	12.85%
O3	1.17%	2.34%	1.82%	5.47%
O4	3.13%	5.47%	8.33%	5.21%
O5	0.39%	0.39%	4.95%	1.82%
Average rejection rate	3.59%	2.73%	4.79%	5.12%

Table 1. Proportion of trials rejected due to eye movements for each observer and experimental condition.

for 96.41%, 97.27%, 95.21%, and 94.88% of the trials in segmented and unsegmented conditions of Experiments 1 and 2, respectively (Table 1).

Statistical analysis of behavioral data

As performance was similar for contrast changes on the left and right, these trials were combined. We plotted the percentage of trials in which the observer judged the test contrast "higher" as a function of the contrast change. A cumulative normal function was fitted to the data by probit analysis (Finney, 1971; McKee, Klein, & Teller, 1985; Morgan, Watamaniuk, & McKee, 2000). Threshold was defined as the contrast change required to achieve performance one standard deviation from the mean of the cumulative normal function. The slope of the psychometric function corresponds to the reciprocal of the standard deviation, σ, of the fitted normal function. The steeper the slope, the more sensitive the observer is to the contrast change. All statistical analyses were performed on standard deviations (1/slope) of the normal curves.

Results

Experiment 1: Fixed target location on segmented and unsegmented backgrounds

In separate blocks, observers detected a contrast change on a target that was either segmented or contiguous with the surrounding texture. Observers reported the sign of the contrast change on the cued side while maintaining fixation at the center of the display.

Figure 2 plots the proportion of trials in which the contrast change was judged to be an increment as a function of the physical contrast change. Separate cumulative normal functions were fitted to each observer's data for the segmented and unsegmented conditions. We performed a one-way ANOVA on the standard deviations (i.e., 1/slope) of the normal curves to determine if the sensitivity to a target was significantly influenced by the segmentation of the target from the surround. The statistical test showed that observers' sensitivity to a target that occurred at a fixed location was enhanced when the target was segmented compared to when the target was contiguous with the surround, $F(1, 9) = 19.7496$, $p = 0.0113$.

Experiment 2: Uncertain target location on segmented and unsegmented backgrounds

To determine how sensitivity to a target changes depending upon the task and the surround, we repeated Experiment 1, but the target could now appear with equal probability in one of the three possible locations from trial to trial (see Figure 1b). Observers were cued to attend to either the left or the right and were asked to perform a contrast-discrimination task on the cued side. Because the observer did not know exactly where the target would appear, he or she had to attend to all

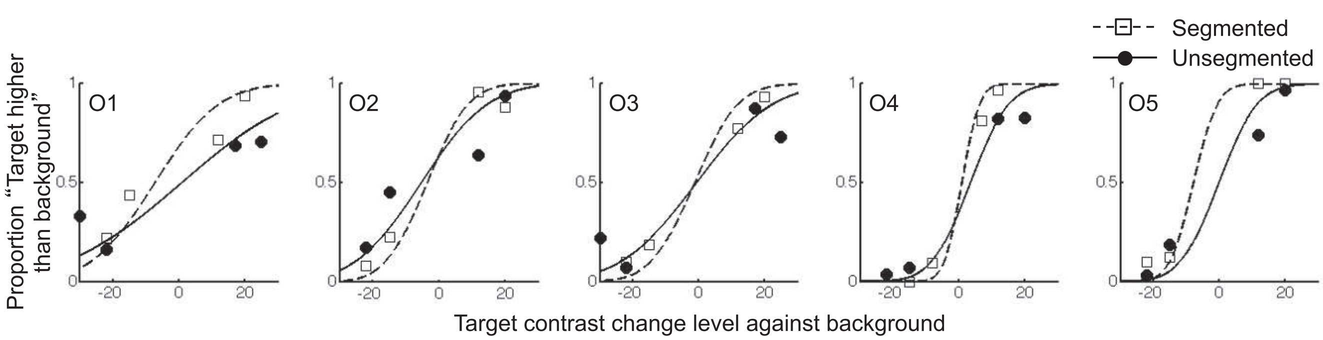

Figure 2. Proportion of trials in which the observer judged the center contrast to be higher than the background contrast for the segmented (dashed lines) and unsegmented (continuous lines) conditions, respectively. In this experiment, the target always appeared at a fixed location at the center of the grating texture.

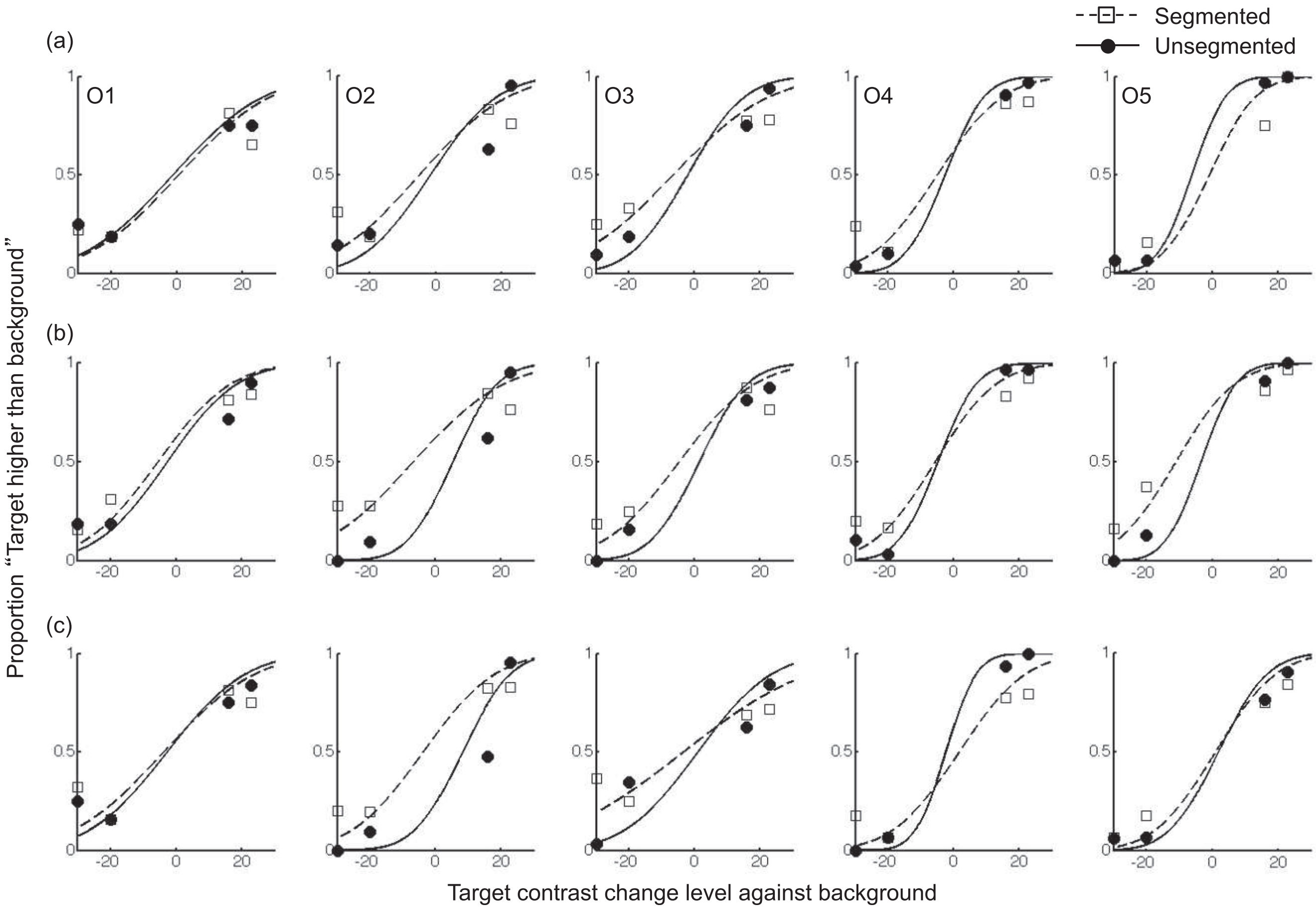

Figure 3. Proportion of trials in which the contrast was judged higher than the background as a function of the contrast change value. Dashed and continuous lines plot data for the segmented and unsegmented conditions, respectively. The target appeared at three possible locations on the background texture as shown in Figure 1b. Each column shows data for one observer, and each row shows data for a particular location: (a) target at center, (b) target 1.2° from center, (c) target 2.3° from center.

three locations to the best of his or her ability. This task is similar to a traditional visual search task in which the observer is uncertain about target location.

Figure 3 shows psychometric functions when the target appeared at one of the three possible locations in the segmented (dashed line) and unsegmented (continuous line) conditions. Figure 4 plots the thresholds at all three locations in both conditions. A two-way ANOVA on the thresholds (standard deviations) of psychometric functions confirmed that there is a significant main effect of segmentation on the slopes of psychometric functions, $F(1, 4) = 16.6503$, $p = 0.0151$. It is clear that when target location was uncertain, contrast discrimination was significantly more difficult in the segmented configuration than in the unsegmented configuration. Moreover, this pattern was evident at all three locations within a configuration.

Figure 5 compares thresholds at the center location in the fixed and uncertain location conditions. Recall that the grating surrounding the central target in the segmented and unsegmented conditions was unchanged in Experiment 2. When the location of the target was uncertain, observers were more sensitive to changes in contrast on an unsegmented background than on a segmented background. This trend is opposite to that observed for the fixed condition. Another important point to note is that increasing the uncertainty of target locations from one to three has no effect on sensitivity when the change occurs on an unsegmented background, but increasing uncertainty has a significant detrimental effect on a segmented background. To investigate the interaction of segmentation and uncertainty on contrast sensitivity, we performed a statistical test on the sensitivity to a target that appeared at the central location in Experiments 1 and 2. A two-factor, within-subject, repeated-measures ANOVA clearly showed a significant interaction between position uncertainty and texture segmentation, $F(1, 4) = 12.8901$, $p = 0.023$. Position uncertainty significantly elevated contrast thresholds on the segmented background, $F(1, 9) = 40.7063$, $p = 0.0031$, while it did not have an effect on contrast thresholds on the unsegmented background.

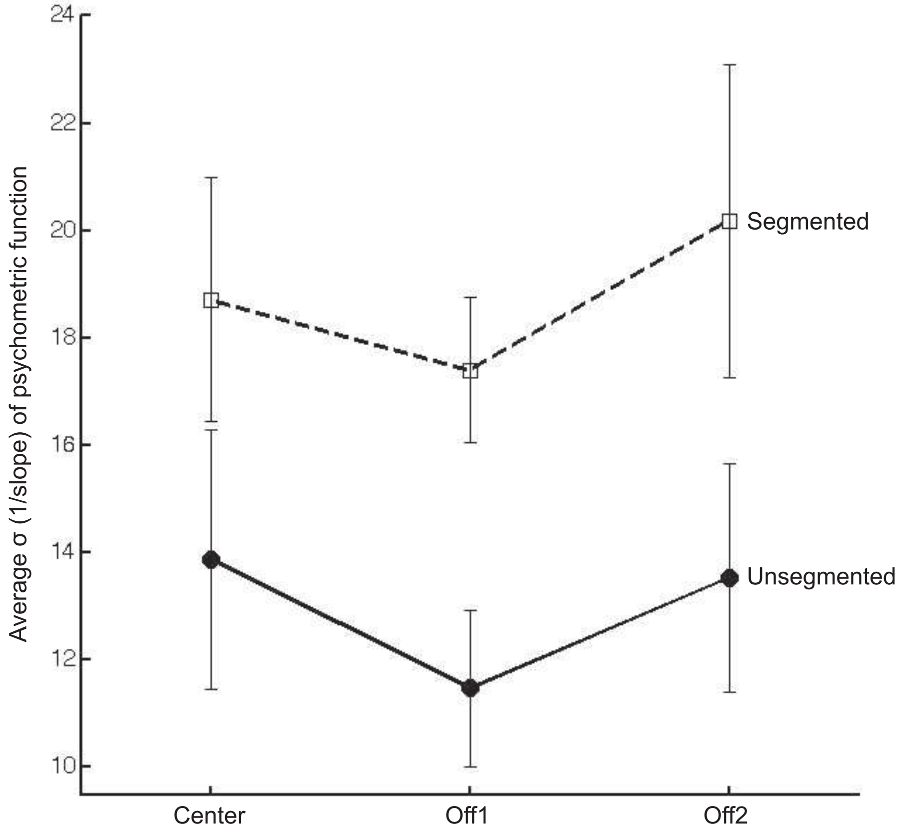

Figure 4. Average thresholds (standard deviations of psychometric functions) at each target location: center, off1 (1.2° offset from center), and off2 (2.3° offset from center). The dashed and continuous lines represent the standard deviations of the normal curves at three locations on the segmented background and unsegmented backgrounds, respectively. The error bar represents the standard error across five observers.

General discussion

To understand how task-dependent selective attention interacts with midlevel texture segmentation, we investigated how human observers discriminated contrast change on a textured background. We measured the sensitivity to contrast changes by manipulating two experimental variables that are not usually studied together in contrast discrimination experiments: position uncertainty and background texture segmentation. We demonstrated that the contrast sensitivity varied with surrounding context and with position uncertainty. In Experiment 1, in which the contrast change occurred at a fixed location, contrast sensitivity was significantly higher when the region of the contrast change was segmented from the rest of the texture. This new finding demonstrates that sensitivity at a known location depends on the segmentation of the target from the surround texture. In Experiment 2, in which the contrast change occurred in one of three locations, contrast sensitivity was lower on the segmented background than on the unsegmented background. The two experiments taken together show another new result: When the target is continuous with background texture, it is immune from the changes in sensitivity that usually occur with varying location uncertainty. Thresholds for detecting a contrast change neither increase with increasing position uncertainty nor show the increased sensitivity associated with a known segmented location. That contrast thresholds for detecting a contrast change on a continuous smooth background do not depend on the number of potential target locations suggests that observers are not monitoring individual locations. Instead, they report that they are monitoring discontinuities across a single smooth surface. This strategy, although not as sensitive as detecting a contrast change at a fixed location that is segmented from the surround, is very effective at finding a target at an unknown location. This finding is consistent with previous reports that attention spreads within a perceptually grouped object (Driver & Baylis, 1998; Driver et al., 2001; Duncan, 1984; He & Nakayama, 1995) and that context homogeneity facilitates visual search for an embedded task-relevant stimulus (Akyürek et al., 2010; Bravo & Nakayama, 1992; Duncan & Humphreys, 1989; He & Nakayama, 1995; Meinecke & Donk, 2002; Schubö et al., 2007).

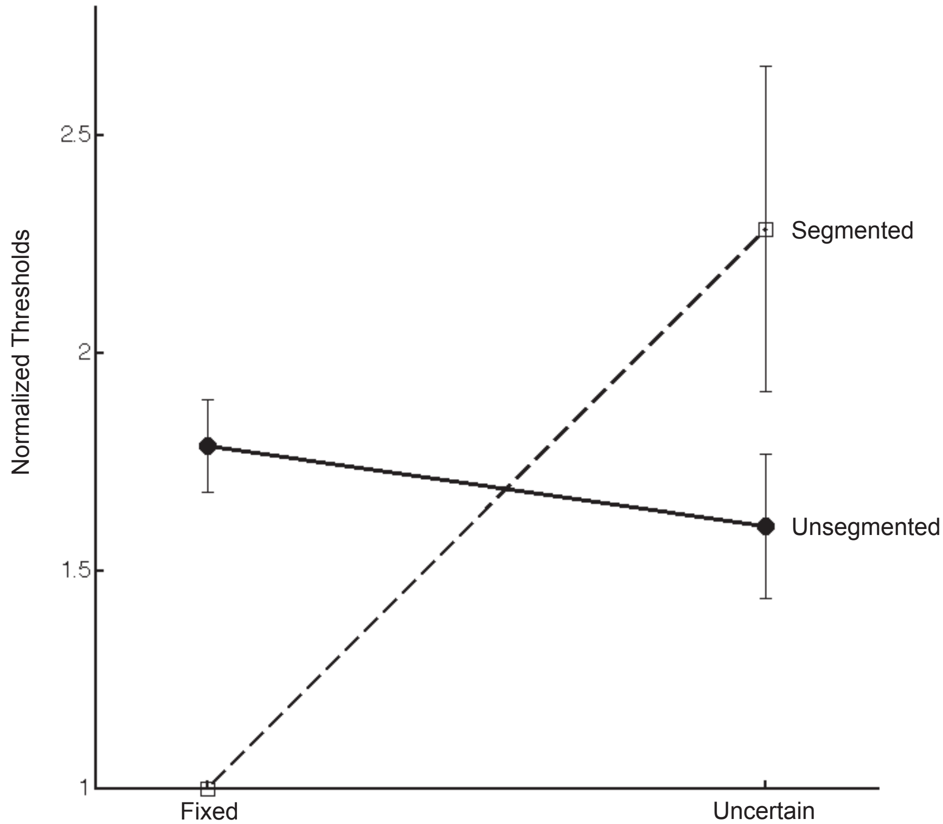

Figure 5. Normalized thresholds for detecting a contrast change at the center of a texture when the change occurs at a fixed location (Experiment 1) or at one of three possible locations (Experiment 2). For each observer, thresholds are normalized to that for the fixed, segmented condition. The dashed and continuous lines represent thresholds in the segmented and unsegmented background texture conditions, respectively. The error bar represents the standard error across five observers.

Does attention select spatial locations or objects as a substrate? The two perspectives are not mutually exclusive and may concern different, but complementary, mechanisms. In divided spatial attention, multiple stimuli (typically placed at different locations) are processed. If the task is sufficiently difficult (Duncan & Humphreys, 1989), this leads to a performance decrement compared to a one-stimulus condition. Does the interference arise in processing different locations or in processing different objects in the scene? Our experiment shows that attention strongly interacts with texture segmentation as well as uncertainty about the target. The segmentation/grouping of the texture backgrounds appear ideally suited to two conditions: The segmented texture facilitates detecting a contrast change at the segmented location (dashed line in Figure 5) whereas the continuous texture facilitates detecting a contrast change at any location across the surface (continuous line in Figure 5). In other words, when the contrast change appears at a fixed position that is isolated from the surrounding texture, segmentation aids the selection of the target location, but when the contrast change occurs at an unknown location on a continuous texture, the grouping of the surface as a single entity aids in detecting the change. This same discontinuity-detection mechanism appears to detect contrast changes on the unsegmented surface regardless of whether the location of the change is known or uncertain.

When the surround texture is segmented and target location is uncertain, a combination of factors appears to come into play. Previous models of visual search predict that a three-fold increase in uncertainty for independent locations should increase threshold by a factor of 1.65 for a single interval task that requires the observer the report the sign of the change (Baldassi & Verghese, 2002). However, in our experiments, a threefold increase in location uncertainty increased thresholds by a factor of >2.25 across observers, suggesting that it is more difficult to attend simultaneously to one location that is clearly segmented and to two that are not than to three independent locations. In fact, our supplemental data bear this out. Here we repeated the uncertainty experiment on the segmented surface but introduced gaps around the three potential locations so that they were segmented from the background. Figure S1 shows that thresholds increase by about a factor of 1.85 $\pm$ 0.34 relative to the fixed location threshold, which is close to the predicted increase for three independent locations.

Relationship to previous attention studies

Previously, we showed that the spatial extent of attention depends on segmentation of the display (Kim & Verghese, 2012). Using a similar center-surround configuration and steady-state EEG, we characterized the spread of attention by the modulation of a flickering annulus that surrounded the target grating. When the target grating was clearly segmented from the annulus, the flickering annulus showed strong modulation, indicating that attention was broadly focused over the target and spilled over into the surround. However, as the degree of segmentation of the target from the annulus decreased, so did the modulation of the surround, indicating that spatial attention was increasingly focused on the target. Thus, when the target appeared at a known location on an unsegmented surface, observers had to narrow their focus of attention to counteract the grouping of the target with the surrounding annulus (Kim & Verghese, 2012). This seems, at first, to be at odds with the preceding literature that attention spreads over a surface, leading to the expectation that the modulation of the surrounding grating would be greatest in the unsegmented condition. To achieve the same level of performance regardless of the degree of segmentation, we found that we had to increase the magnitude of the contrast increment in the least-segmented configuration. This is consistent with our current results plotted on the left side of Figure 5. For the fixed target location, contrast thresholds were higher on the unsegmented background than on the segmented background. That it is harder to detect changes on an unsegmented target is consistent with Freeman and Verghese (2009), who measured contrast discrimination on drifting gratings. In this study, the contrast change always occurred on a horizontal grating upon which an orthogonal drifting grating was superimposed. Contrast discrimination was hard when the two gratings cohered to form a plaid but was easier under conditions in which the two gratings appeared segregated. Specifically, the ease of contrast discrimination was directly related to a measurement of the perceived segregation of the gratings (Freeman & Verghese, 2009).

Our results are also in line with previous studies showing that observers are better at judging two attributes of one object than at judging two attributes distributed across different objects (Baylis & Driver, 1993; Duncan, 1984, 1993a, 1993b; Kramer, Weber, & Watson, 1997; Lavie & Driver, 1996; Vecera & Farah, 1994). In object-based models (Duncan, 1984), perceptual resources are allocated to higher-level entities, created by lower-level processes of grouping and scene segmentation. The higher-level entities can be objects (Duncan, 1984), perceptual groups (Duncan & Humphreys, 1989), or surfaces (He & Nakayama, 1995; Nakayama & He, 1995). Duncan (1984) used a box and a superimposed line that were briefly displayed. Two judgments concerning attributes of one object could be performed simultaneously without loss of accuracy (as compared with a single judgment) whereas accuracy was impaired when the two judgments concerned attributes from different objects. Our uncertainty data hint at such an object-based effect ("Uncertain" data in Figure 5). When observers look for a contrast change in the segmented condition, they are making judgments on two surfaces: the center and the surround. When the change can occur on either the center or surround, performance declines analogous to the decrement associated with reporting features on two different objects/surfaces. In comparison, contrast changes on the unsegmented texture involve judgments only on a single surface. This might explain why location uncertainty has little effect on contrast-change detection

According to object-based models, the spread of attention is strictly dependent on the segmentation of the visual scene. In these models, attention is directed toward perceptual objects, created either by the gestalt principles of scene organization or related early processes (S. Palmer & Rock, 1994). Therefore, a weak segmentation of the image into different perceptual groups should hamper the selective allocation of attention. He and Nakayama (1995) found that, during spatial cueing experiments using stereoscopic images, attention spread across a surface even if the surface spanned a range of stereoscopic depths. Their study offers a compelling demonstration of the advantage of a common surface representation when searching for items that lie on that surface. Belonging to the same surface (a form of perceptual grouping) produced larger attentional benefits than proximity in three-dimensional space whereas having to shift attention between surfaces was more costly than moving a larger distance along the same surface. Here we show that the obligatory grouping that occurs within a surface comes at a cost. Selectivity for a fixed location on the surface is poor compared to the case in which that location is separated from the rest of the surface by a gap ("Fixed" data in Figure 5).

There is an alternate account for an obligatory spread of attention across an object. Previous studies (Shomstein & Yantis, 2002, 2004; Drummond & Shomstein, 2010) propose that the nature of the task dictates whether attention is confined to a location or spreads within an object. In their experiments, the crucial factor that defines whether a single location or an entire object receives priority is uncertainty about target location. When the target always occurred at a known location, attention was confined to that location and did not spread within the object. However, when target location was unknown, attention spread within an object. Our result with uncertain locations is fully compatible with the spread of attention within an object and with the cost of attending to locations across different objects ("Uncertain" data in Figure 5). However, our result with the target at a fixed location on an unsegmented surface indicates that observers have difficulty selectively attending to that location ("Fixed" data in Figure 5). There are several reasons for this discrepancy: (a) The targets and flankers in Shomstein and Yantis (2002) were not exactly embedded in the background texture whereas our unsegmented target certainly appeared to be part of the background. (b) Their target was visible throughout the trial, whereas the target in our experiments appeared briefly at an unknown time in the trial. (c) In the fixed location condition of Shomstein and Yantis (2002), the target was at the center of the display whereas our fixed location was 5° in the periphery, where midlevel segmentation effects might be harder to overcome.

Is it possible that the pattern of sensitivity in our experiments is due to center-surround interactions? Traditionally, neuronal responses to center-surround type stimuli have been explained by a divisive gain control mechanism that divides the response of a neuron by a weighted sum of the responses of neighboring neurons (Carandini, Heeger, & Movshon, 1997; Heeger, 1992; Schwartz & Simoncelli, 2001). It can be argued that the isolated target condition experiences less surround suppression because of the 0.25° gap around it. However, Appelbaum, Wade, Pettet, Vildavski, and Norcia (2008) measured steady-state responses to a flickering center embedded in a surround and showed that the evoked response to the center was independent of the size of the gap between center and surround. Moreover, if the higher sensitivity to a contrast change at a fixed location were due to the gap in the isolated condition, then the gap should have also enhanced contrast sensitivity to the segmented target in the uncertain condition. To the contrary, we find that sensitivity for an isolated target in the uncertain condition is significantly worse than when the target is contiguous with the surround. A more parsimonious explanation for these results is that it is harder to find a target that can appear on one of two different surfaces than on a single surface.

How do higher-level task demands modulate midlevel processes, such as segmentation and surface representation? The earliest visual cortical area (V1) shows a texture segmentation response that occurs about 60 ms after its initial response to the visual stimulus, suggesting feedback from higher areas (Lamme, 1995; Lamme, Rodriguez-Rodriguez, & Spekreijse, 1999; Rossi, Desimone, & Ungerleider, 2001). Specifically, lesions to area V4 impair a monkey's ability to segregate texture (De Weerd, Desimone, & Ungerleider, 1996; Merigan, 1996). Thus, it appears that midlevel areas between V1 and V4 are involved in texture segmentation and that the delayed activity in V1 is due to feedback from V4. Functional imaging in humans supports the role of these areas in texture segmentation (Kastner, De Weerd, & Ungerleider, 2000; Scholte, Witteveen, Spekreijse, & Lamme, 2006). These same visual areas (V1 and ventral occipital areas) are also thought to serve as the physiological basis of the spotlight of visual spatial attention (Brefczynski & DeYoe, 1999; Hansen, Kay, & Gallant, 2007; Tootell et al., 1998). A recent review paper (Roe et al., 2012) proposes visual area V4 as the cortical locus at which top-down attentional modulation interacts with midlevel processes that segment the visual scene. According to this proposal, the unifying function of V4 circuitry is to enable "selective extraction" whether it is by bottom-up texture segmentation or by attentionally driven spatial- or feature-based selection (Roe et al., 2012).

Conclusion

We set out to determine how top-down knowledge about the location of the target interacts with midlevel processes that segment the visual scene. Our results show that both location uncertainty and the contiguity of the target with the surrounding surface determine perceptual sensitivity. When the target location is known, sensitivity is best for an isolated target and declines significantly when the target is contiguous with the surround. Increased uncertainty about target location causes sensitivity to decline in the isolated condition but remain unchanged in the contiguous condition, showing a benefit for targets on a single surface. Thus, the effect of uncertainty on target selection depends on surface organization.

Keywords: target selection, texture segmentation, location uncertainty, surface organization

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References

Akyürek, E., Dinkelbach, A., Schubö, A., & Müller, H. (2010). Electrophysiological correlates of detecting a visual target and detecting its absence: the role of feature dimensions. *Neuropsychologia, 48*, 3365–3370.

Appelbaum, L. G., Wade, A. R., Pettet, M. W., Vildavski, V. Y., & Norcia, A. M. (2008). Figure-ground interaction in the human visual cortex. *Journal of Vision*, *8*(9):8, 1–19, http://www.journalofvision.org/content/8/9/8, doi:10.1167/8.9.8. [PubMed] [Article]

Baldassi, S., & Verghese, P. (2002). Comparing integration rules in visual search. *Journal of Vision, 2*(8):3, 559–570, http://www.journalofvision.org/content/2/8/3, doi:10.1167/2.8.3. [PubMed] [Article]

Baylis, G. C., & Driver, J. (1993). Visual attention and objects: Evidence for hierarchical coding of location. *Journal of Experimental Psychology: Human Perception and Performance, 19*(3), 451–470.

Bravo, M. J., & Nakayama, K. (1992). The role of attention in different visual-search tasks. *Perception & Psychophysics*, *51*(5), 465–472.

Brefczynski, J. A., & DeYoe, E. A. (1999). A physiological correlate of the 'spotlight' of visual attention. *Nature Neuroscience*, *2*(4), 370–374.

Carandini, M., Heeger, D. J., & Movshon, J. A. (1997). Linearity and normalization in simple cells of the macaque primary visual cortex. *Journal of Neuroscience*, *17*(21), 8621–8644.

Cohn, T. E., & Lasley, D. J. (1974). Detectability of a luminance increment: Effect of spatial uncertainty. *Journal of the Optical Society of America, 64*(12), 1715–1719.

Davis, E. T., Kramer, P., & Graham, N. (1983). Uncertainty about spatial frequency, spatial position, or contrast of visual patterns. *Perception & Psychophysics*, *33*(1), 20–28.

De Weerd, P., Desimone, R., & Ungerleider, L. G. (1996). Cue-dependent deficits in grating orientation discrimination after V4 lesions in macaques. *Visual Neuroscience*, *13*(3), 529–538.

Driver, J., & Baylis, G. (1998). Attention and visual object perception. In R. Parasuraman (Ed.), *The attentive brain* (pp. 299–326). Cambridge, MA: MIT Press.

Driver, J., Davis, G., Russell, C., Turatto, M., & Freeman, E. (2001). Segmentation, attention and phenomenal visual objects. *Cognition, 80*(1–2), 61–95.

Drummond, L., & Shomstein, S. (2010). Object based attention: shifting or uncertainty. *Attention, Perception, & Psychophysics*, *72*, 1743–1755.

Duncan, J. (1993a). Coordination of what and where in visual attention. *Perception*, *22*(11), 1261–1270.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General*, *113*(4), 501–517.

Duncan, J. (1993b). Similarity between concurrent visual discriminations: Dimensions and objects. *Perception & Psychophysics, 54*(4), 425–430.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, *96*(3), 433–458.

Finney, D. J. (1971). *Probit analysis* (3rd ed.). Cambridge, UK: University Press.

Foley, J. M., & Schwarz, W. (1998). Spatial attention: The effect of position uncertainty and number of distractor patterns on the threshold versus contrast function for contrast discrimination. *Journal of the Optical Society of America A. Optics and Image-science, 15,* 1036–1047.

Freeman, E., & Verghese, P. (2009). Peeling plaids apart: Context counteracts cross-orientation masking. *PLoS One*, *4*(12), e8123.

Hansen, K. A., Kay, K. N., & Gallant, J. L. (2007). Topographic organization in and near human visual area V4. *Journal of Neuroscience*, *27*(44), 11896–11911.

He, Z. J., & Nakayama, K. (1995). Visual attention to surfaces in three-dimensional space. *Proceedings of the National Academy of Sciences, USA, 92*(24), 11155–11159.

Heeger, D. J. (1992). Normalization of cell responses in cat striate cortex. *Visual Neuroscience*, *9*(2), 181–197.

Kastner, S., De Weerd, P., & Ungerleider, L. G. (2000). Texture segregation in the human visual cortex: A functional MRI study. *Journal of Neurophysiology*, *83*(4), 2453–2457.

Kim, Y. J., & Verghese, P. (2012). The selectivity of task-dependent attention varies with surrounding context. *Journal of Neuroscience, 32*(35), 12180–12191, doi:10.1523/JNEUROSCI.5992-11.2012.

Kramer, A. F., Weber, T. A., & Watson, S. E. (1997). Object-based attentional selection—Grouped arrays or spatially invariant representations? Comment on Vecera and Farah (1994). *Journal of Experimental Psychology: General, 126*(1), 3–13.

Laarni, J., Näsänen, R., Rovamo, J., & Saarinen, J. (1996). Performance in simple visual search at threshold contrasts. *Investigative Ophthalmology* *and Visual Science, 37*(8), 1706–1710, http://www.iovs.org/content/37/8/1706. [PubMed] [Article]

Lamme, V. A. (1995). The neurophysiology of figure-ground segregation in primary visual cortex. *Journal of Neuroscience*, *15*(2), 1605–1615.

Lamme, V. A., Rodriguez-Rodriguez, V., & Spekreijse, H. (1999). Separate processing dynamics for texture elements, boundaries and surfaces in primary visual cortex of the macaque monkey. *Cerebral Cortex*, *9*(4), 406–413.

Lavie, N., & Driver, J. (1996). On the spatial extent of attention in object-based visual selection. *Perception & Psychophysics*, *58*(8), 1238–1251.

McKee, S. P., Klein, S. A., & Teller, D. Y. (1985). Statistical properties of forced-choice psychometric functions: Implications of probit analysis. *Perception & Psychophysics, 37*(4), 286–298.

Meinecke, C., & Donk, M. (2002). Detection performance in pop-out tasks: Nonmonotonic changes with display size and eccentricity. *Perception, 31*(5), 591–602.

Merigan, W. H. (1996). Basic visual capacities and shape discrimination after lesions of extrastriate area V4 in macaques. *Visual Neuroscience*, *13*(1), 51–60.

Morgan, M. J., Watamaniuk, S. N., & McKee, S. P. (2000). The use of an implicit standard for measuring discrimination thresholds. *Vision Research*, *40*(17), 2341–2349.

Nakayama, K., & He, Z. J. (1995). Attention to surfaces: Beyond a Cartesian understanding of visual attention. In T. V. Papathomas (Ed.), *Early vision and beyond* (pp. 181–188). Cambridge, MA: M.I.T. Press.

Palmer, J., Ames, C. T., & Lindsey, D. T. (1993). Measuring the effect of attention on simple visual search. *Journal of Experimental Psychology: Human Perception & Performance*, *19*(1), 108–130.

Palmer, J., Verghese, P., & Pavel, M. (2000). The psychophysics of visual search. *Vision Research, 40*(10–12), 1227–1268.

Palmer, S., & Rock, I. (1994). Rethinking perceptual organization: The role of uniform connectedness. *Psychonomic Bulletin & Review*, *1*(1), 29–55.

Roe, A. W., Chelazzi, L., Connor, C. E., Conway, B. R., Fujita, I., Gallant, J. L., & Vanduffel, W. (2012). Toward a unified theory of visual area V4. *Neuron, 74*(1), 12–29, doi: S0896-6273(12)00274-7 [pii] 10.1016/j.neuron.2012.03.011.

Rossi, A. F., Desimone, R., & Ungerleider, L. G. (2001). Contextual modulation in primary visual cortex of macaques. *Journal of Neuroscience*, *21*(5), 1698–1709.

Scholte, H. S., Witteveen, S. C., Spekreijse, H., & Lamme, V. A. (2006). The influence of inattention on the neural correlates of scene segmentation. *Brain Research, 1076*(1), 106–115, doi:10.1016/j.brainres.2005.10.051.

Schübo, A., Wykowska, A., & Müller, H. J. (2007). Detecting pop-out targets in contexts of varying homogeneity: Investigating homogeneity coding with event-related brain potentials (ERPs). *Brain Research, 1138,* 136–147, doi:10.1016/j.brainres.2006.12.059.

Schwartz, O., & Simoncelli, E. P. (2001). Natural signal statistics and sensory gain control. *Nature Neuroscience*, *4*(8), 819–825.

Shomstein, S., & Yantis, S. (2002). Object-based attention: sensory modulation or priority setting? *Perceptions & Psychophysics*, *64*, 41–51.

Shomstein, S., & Yantis, S. (2004). Configural and contextual prioritization in object-based attention. *Perceptions & Psychophysics*, *11*, 247–253.

Tootell, R. B., Hadjikhani, N., Hall, E. K., Marrett, S., Vanduffel, W., Vaughan, J. T., & Dale, A. M. (1998). The retinotopy of visual spatial attention. *Neuron, 21*(6), 1409–1422.

Valdes-Sosa, M., Cobo, A., & Pinilla, T. (2000). Attention to object files defined by transparent motion. *Journal of Experimental Psychology: Human Perception & Performance*, *26*(2), 488–505.

Vecera, S. P., & Farah, M. J. (1994). Does visual attention select objects or locations? *Journal of Experimental Psychology: General*, *123*(2), 146–160.