Spatial selection and target identification are separable processes in visual search

Shahab Ghorashi Harvard University, USA

James T. Enns University of British Columbia, Canada

Raymond M. Klein Dalhousie University, Canada

Vincent Di Lollo Simon Fraser University, Canada

Visual search involves deciding both where to look (spatial selection) and whether any given object is a target or a non-target (identification). The aim of the present study was to determine whether these two functions are separable in performance. Spatial selection was manipulated by an exogenous cue and identification was manipulated by whether a second target appeared after a short or long delay following a first target (the attentional blink, AB). Experiment 1 indicated an additive relation between non-informative spatial cueing and the AB, pointing to independent spatial and identification processes. Experiment 2 tested an informative spatial cue with similar results. Experiment 3 also showed an additive relationship, using a response measure that avoided possible floor effects. We interpret the separability of spatial selection and identification as reflecting the independent operation of dorsal and ventral visual pathways, respectively, at least at the early stages of processing.

Keywords: attention, visual search, spatial selection, identification, attentional blink

Citation: Ghorashi, S., Enns, J. T., Klein, R. M., & Di Lollo, V. (2010). Spatial selection and target identification are separable processes in visual search. *Journal of Vision, 10*(3):7, 1–12, http://journalofvision.org/10/3/7/, doi:10.1167/10.3.7.

Introduction

Observers in a typical visual search experiment are required to find a target object that is randomly located among other distractor objects. In the course of their search, observers must coordinate two mental operations: locating the target within the search display and extracting the identity of objects so as to discriminate targets from distractors. Considerable theorizing has been devoted to the question of the temporal order of these two operations, with some (e.g., Treisman & Gelade, 1980) arguing for identity extraction prior to spatial localization, while others (e.g., Julesz, 1984) arguing for spatial localization prior to identity extraction (but see Green, 1991, 1992). However, here we address an even more fundamental question—one that has not been given a great deal of attention to date—namely, whether spatial selection and identity extraction are dissociable functions.

In our view, the question of *dissociability* (or equivalently *separability*) of these two mental operations has logical priority over the question of whether one of these operations is performed before the other. If the operations are separable, the relative ordering of the operations can then be explored as a secondary question. However, if these operations are inseparable, because they both rely on common cognitive resources, then the question of relative ordering becomes moot. In the sections that follow, we briefly review past theoretical and empirical contributions to this question, before turning to a series of three experiments that examine this question in a new way.

Theories of visual search differ in the emphasis they place on the processes of spatial selection and identification. For example, the most influential framework for interpreting visual search has been *Feature Integration Theory* (FIT; Treisman & Gelade, 1980), which holds that visual features such as color and shape are initially registered in separate topographically organized regions of the brain. In order to identify any particular conjunction of features as belonging to the same object, information from remote brain regions must be combined (the metaphor of attention as "glue" was used in early papers on FIT, the term "binding" is used in more recent papers). The integration of features requires a master map of spatial locations to which all feature maps have access. Moreover, feature integration is inherently a serial operation; it can only be done one location (or object) at a time. According to FIT, visual search tasks are slow and effortful when feature integration must be performed for each item in the display until the target is found. Search tasks become faster and easier when the target item can be identified on the basis of unique activity in a single feature map. No linking of different feature maps is required and so the master map can be consulted directly.

doi: 10.1167/10.3.7 Received September 18, 2009; published March 25, 2010 ISSN 1534-7362 © ARVO

Although Feature Integration Theory has undergone several modifications since its inception (Treisman, 1988; Treisman & Gormican, 1988; Treisman & Sato, 1990), it still proposes that the limiting factor on search efficiency is the feature integration process, not the step of spatially localizing the conjoined features in the search display. Note that the main theoretical alternatives to this theory also place more emphasis on identity extraction than on spatial localization. For example, *resemblance theory* (Duncan & Humphreys, 1989) proposes that similarity relations among the display items limit search efficiency, both similarity relations of targets to distractors and those among the distractors. Wolfe's (1994, 2006) *guided search* theory also highlights inter-item relationships, though it does so through the complexity of the interactions among feature maps that are needed to define a target as distinct from the distractors.

In contrast to this emphasis on identity extraction, other theories of visual search have placed greater emphasis on the control of an attentional spotlight or zoom lens that enhances processing within a limited region of space (Eriksen & Yeh, 1985; Posner, 1980). The most comprehensive theory of this kind is *texton theory* (Julesz, 1984; Sagi & Julesz, 1985a, 1985b), which holds that target identification occurs only after an initial stage of processing in which the visual image has been analyzed for spatially localized discontinuities in simple visual features. Discontinuity localization is said to be a parallel process, though its efficiency is still a function of the strength of the signal that is derived from the discontinuity at any given location. Furthermore, registration of features in a given location is a serial process, leading to the prediction that the location of a spatial discontinuity in a display will invariably occur prior to the identification of its featural properties.

We note that the possible relations between spatial selection and identification—addressed in the past by the functional theories specifically tailored to account for visual search—are cast in a new light when considered from the perspective of the neurologically inspired dual system theory (Goodale & Milner, 2004; Milner & Goodale, 1995; Ungerleider & Mishkin, 1982). In this framework, space-related information is processed along the dorsal ("Where/How") pathway, while identity-related information is processed along the ventral ("What") pathway. Moreover, studies on animals and human patients with selective injuries to these pathways support this distinction, with damage to the ventral stream compromising object identification while preserving accurate visually guided actions to the same objects, and damage to the dorsal stream compromising action to objects while preserving conscious perception of them.

Despite all these indications, however, the separability of spatial selection and identity extraction that is assumed by this theory is not easy to verify against experimental data in visual search. This is because in studies of visual search to date, experimental factors that influence spatial selection and identity processing have invariably been manipulated concurrently. Consider, for example, the most frequently manipulated factor in visual search studies, that of set size (i.e., the total number of objects in a search array). Increases in set size will impair spatial selectivity by increasing the number of potential target locations, but at the same time such increases will impair identity extraction by decreasing the signal-to-noise ratio (Eckstein, 1998; Palmer, 1995). Thus, existing visual search studies are inadequate for addressing the separability of spatial selection versus identification.

In the present study, we test for separability in visual search by combining two paradigms that have typically been used for other purposes in the study of human attention: exogenous spatial cueing and the attentional blink (AB). The use of exogenous spatial cues (e.g., a high-contrast dot displayed briefly at the expected location of an ensuing target) to direct attention to specific locations in a visual display independently of the objects that appear in those locations has an extensive history, extending at least to Eriksen and Hoffman (1972; also see Klein, 2004). The literature on the AB (Raymond, Shapiro, & Arnell, 1992) is equally extensive (for a review, see Dux & Marois, 2009) involving the detection or identification of targets that are presented among distractor items in a rapid serial visual presentation (RSVP). Here the primary finding is impairment in the identification accuracy of a second target when it is presented less than about 500 ms after a first target. The AB is generally regarded as a high-level phenomenon that interferes with the process of identity extraction (Chun & Potter, 1995; Jolicœur & Dell'Acqua, 1998). Moreover, the AB has been shown not to interfere with the process of spatial selection (Ghorashi, Di Lollo, & Klein, 2007). It is worth emphasizing that in the present study these two paradigms will serve primarily to influence the relative difficulty of spatial selection and identity extraction during a visual search; this is not intended as yet another study of the either spatial cueing or the attentional blink in its own right.

In combining these two paradigms in a visual search study, we rely on additive-factors logic (Sternberg, 1969). Within this framework, it is assumed that mental processing is carried out in a series of non-overlapping stages. If two factors influence independent stages of processing, they will have additive effects on the dependent measure. Conversely, whenever additivity is found, the underlying stages of processing can be assumed to be independent. If, on the other hand, at least one of the factors influences both stages, as evidenced by an interaction between the effects of the two factors on the dependent measure, then the underlying stages of processing are interpreted as not independent. Sternberg (1969, p. 287) expressed the relationship between the additive effects of two factors and the idea of independence of processing stages, as follows:

> Suppose, for example, that we wish to test the following hypothesis, H1: stimulus encoding and response selection are accomplished by different stages, *a* and *b*. This can be tested only jointly with an additional hypothesis, H2: a particular factor, F, influences stage *a* and not *b,* and a particular factor, G, influences stage *b* and not *a*. If F and G are found to be additive, both hypotheses gain in strength. But the falsity of either H1 or H2 could produce a failure of additivity.

Our use of additive-factors logic therefore allows us to test three hypotheses: (a) that spatial cueing affects spatial selection during visual search, (b) that the AB influences identity extraction during visual search, and (c) that spatial selection and identity extraction are two independent stages of processing during a search task. The last hypothesis is clearly the most important for our purposes, but we note that it depends on supporting evidence for the first two hypotheses to have any meaning. If the effects of spatial cueing and the AB combine additively in their joint influence on the response measure, they can be regarded as affecting independent, non-overlapping stages of processing. It can then be concluded that spatial selection and identity extraction are separable processes. If, on the other hand, the effect of cueing is found to interact with the AB, it can be concluded that spatial selection and identity extraction are not entirely independent stages of processing but have at least some stages of processing in common. Thus, the combined use of spatial cueing and the AB, in the context of a visual search task, permits a psychophysical test of the separability of the two functions.

Experiment 1

In Experiment 1, the difficulty of identity extraction was manipulated by varying the temporal lag between two targets presented in the context of an RSVP stream of black letters (distractors), as illustrated in Figure 1. The first target was a white letter (one of 25) appearing at the center of the display; the second target ("T" tilted left or right) was inserted in a circular search array of 5 rotated "Ls". The difficulty of spatial selection was manipulated by a dot presented briefly at one of the 6 locations on the circular search array just prior to the search display. This cue was present on 6/7 trials, and when it was present, it was equally likely to appear in the target location (1/6) as in one of the distractor locations (5/6).

It is already well established that cueing such as this leads to substantial benefits in target identification (e.g., Colegate, Hoffman, & Eriksen, 1973) and that second-target identification is impaired at short inter-target intervals (e.g., Raymond et al., 1992), leading us to expect main effects of each manipulation. The critical issue, however, was whether the benefit conferred by spatial cueing was invariant with inter-target lag or whether it varied across lags. Parallel functions for the validly cued and invalidly cued conditions across lag would be evidence for the separability of spatial selection and

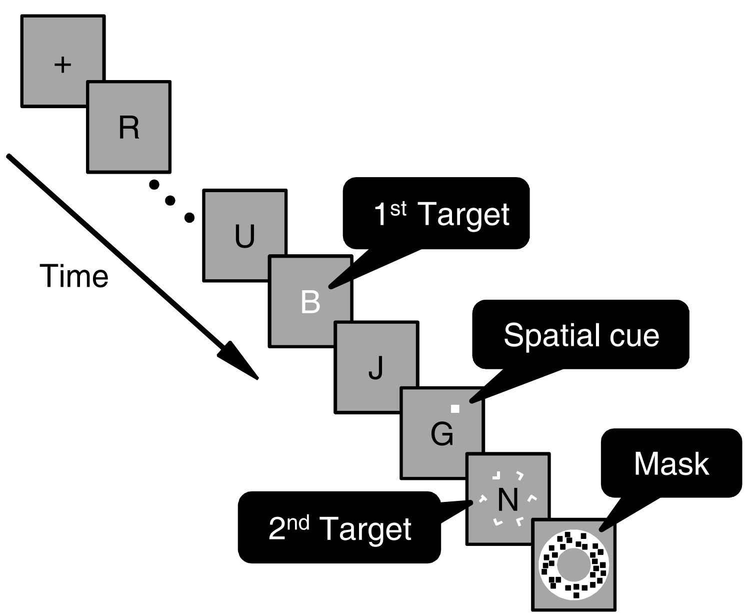

Figure 1. Sequence of events on each trial. On this trial, the second target was invalidly cued.

identity extraction. Interacting functions, on the other hand, would be evidence of interdependence.

Methods

Observers

Twelve undergraduate students at the University of British Columbia participated for course credit. All reported normal or corrected-to-normal vision.

Apparatus and stimuli

Stimuli were displayed on an NEC AccuSync 70 color monitor controlled by an IBM-compatible microcomputer. The background was mid-gray and contained a black fixation cross that subtended 0.5° of visual angle at the center of the screen. The stimuli in the central RSVP stream consisted of black upper case letters (distractors) and a white upper case letter (the first target), all subtending 0.6° of visual angle vertically. The search array containing the second target consisted of 5 randomly rotated "Ls" and one tilted "T" (the target). The letters in the search array subtended 0.5° of visual angle vertically. The "T" was tilted 45° either to the left or to the right. The stimuli in the search array were spaced regularly around an imaginary circle of 2.5° radius, centered at fixation.

Procedure

All displays were viewed from a distance of approximately 60 cm. At the beginning of each trial, the fixation cross was presented in the center of the screen. Observers initiated each trial by pressing the space bar, at which point the fixation cross disappeared and the RSVP sequence began after a random delay of 400–800 ms. The distractors (black letters) in the RSVP stream were drawn randomly without replacement from the English alphabet excepting Q. Each letter was displayed for 40 ms and was separated from the next letter by an inter-stimulus interval (ISI) of 50 ms, during which the screen was blank. This resulted in a stimulus-onset asynchrony (SOA) of 90 ms between successive items. The first target was preceded in the RSVP stream by between 5 and 10 distractors, at random.

The search array containing the second target was presented at one of three inter-target lags: Lag 1 (in the frame directly following the first target), Lag 3 (in the third frame after the first target), or Lag 7 (in the seventh frame following the first target). At Lags 3 and 7, distractors continued to be presented throughout the inter-target lag. Each observer performed one block of 504 trials. In any given session, there were 1/7 validly cued trials and 5/7 invalidly cued trials. In the remaining 1/7 of trials, no cue was presented. When present, the cue stayed on the screen for 40 ms in the RSVP frame preceding the search array in one of 6 potential locations on the search array. Thus, the SOA between the cue and the target was 90 ms. The observers were instructed to ignore the spatial cue since it was not informative. In brief, the design of Experiment 1 was a 3 (Cue: absent, valid, invalid) $\times$ 3 (Lags: 1, 3, 7) within-subject factorial.

The circular search array containing the second target was displayed for 180 ms and was followed immediately by a 180-ms doughnut-shaped mask that completely covered the search array. The pixels inside the mask were randomly colored black or white. The RSVP stream of distractors continued while the search array was displayed. Examples of the stimuli and the sequence of events on any given trial are illustrated in Figure 1. At the end of each trial, observers identified the first target by pressing the corresponding key on the keyboard and then indicated whether the second target was tilted to the left or to the right by pressing the left or the right shift key.

Results and discussion

In this and all subsequent experiments, estimates of second-target identification were based only on those trials in which the first target was identified correctly. This procedure is commonly used in AB studies on the grounds that, on trials in which the first target fails to be identified, the source of the error is unknown, thus its effect on second-target processing cannot be evaluated.

The mean percentages of correct responses for the first target were uniformly high and did not differ statistically from one another ($p > 0.10$, No cue = 94.1%, Valid cue = 93.4%, Invalid cue = 94.2%). The mean percentages of correct responses for the second target, on the other hand, did vary with cue and lag and are illustrated in Figure 2. An analysis of variance (ANOVA) performed on the data in Figure 2 comprised two within-subjects factors: Cue (absent, valid, invalid) and Lag (1, 3, 7). The analysis revealed significant effects of Cue, $F(2, 22) = 17.73$, $p < 0.001$, and Lag, $F(2, 22) = 24.81$, $p < 0.001$. The interaction effect was not significant, $F < 1$. In order to comply with Schweickert's (1985) assertion that additive-factors logic can be applied to accuracy scores provided that a log transformation is performed, we replicated the above ANOVA with log-transformed scores with essentially the same outcome: Cue, $F(2,22) = 15.34$, $p < 0.001$; Lag, $F(2,22) = 21.67$, $p < 0.001$; Cue $\times$ Lag, $F(4,44) < 1$.

As shown in Figure 2, accuracy of second-target identification was higher in the validly cued condition than in either the invalidly cued or uncued conditions. It was also higher at longer than at shorter lags. However, most importantly, the facilitation conferred by a valid cue was invariant with lag. Namely, the valid cue was equally effective whether it was presented during the period of the AB—when stimulus processing is expected to be impaired—or beyond that period. Within the framework

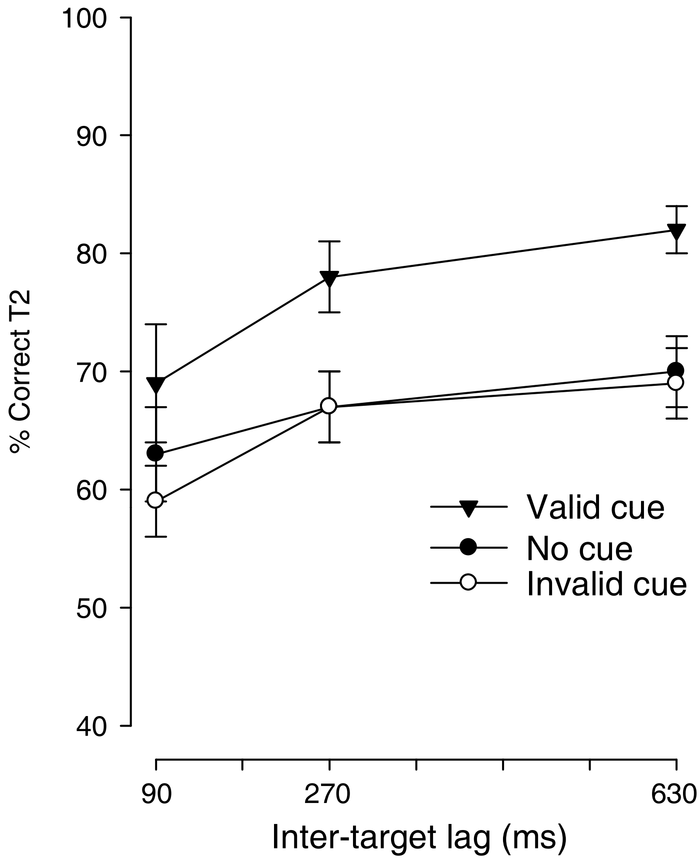

Figure 2. Results of Experiment 1. Bars represent the standard errors of the mean. T2: Second target; ms: milliseconds.

of additive-factors logic, this means that the processes influenced by the cue (spatial selection) and those processes influenced by the AB (identity extraction) are non-overlapping. That is, when two independent experimental factors are used to influence the two putatively separate stages of processing in visual search, and those two factors show additive effects, the independence of those stages of processing is supported.

Experiment 2

In Experiment 2, we tested for separability in a context in which one of the factors influenced search performance much more strongly than the other factor. This is important in order to establish the generality of the finding of additivity in Experiment 1. To increase the effect of spatial cueing, we therefore made the cue informative, so that endogenous and exogenous processes might become involved, and we increased the size of the search array. Previous research has reported that the effect of a cue in a search task increases monotonically with the degree of information provided by the cue (proportion of valid cues; Jonides, 1980; Klein, 2004). Finding additivity with a much stronger cue would therefore increase the generality of the claim that spatial selection and identity extraction are separable in visual search.

Experiment 2 again combined the effect of a spatial cue (No cue, Cue) with that of the AB (Lags 1, 3, 7), but now the cue was 100% informative when it appeared. There were 156 trials in each cue condition, with the order of the two cuing conditions counterbalanced across observers. The set size of the search array was 12 (instead of 6 in Experiment 1). Twelve new observers were tested, though in all other respects the method was the same as in Experiment 1.

Results and discussion

The mean percentages of correct responses for the first target were 88.9% in the Cue condition and 90.7% in the No cue condition. The mean percentages of correct identification of the second target at each lag are illustrated in Figure 3. An ANOVA performed on the data in Figure 3 comprised two within-subjects factors: Cue (present, absent) and Lag (1, 3, 7). The analysis revealed significant effects of Cue, $F(1, 11) = 99.14$, $p < 0.001$, and Lag, $F(2, 22) = 5.99$, $p = 0.008$. The interaction

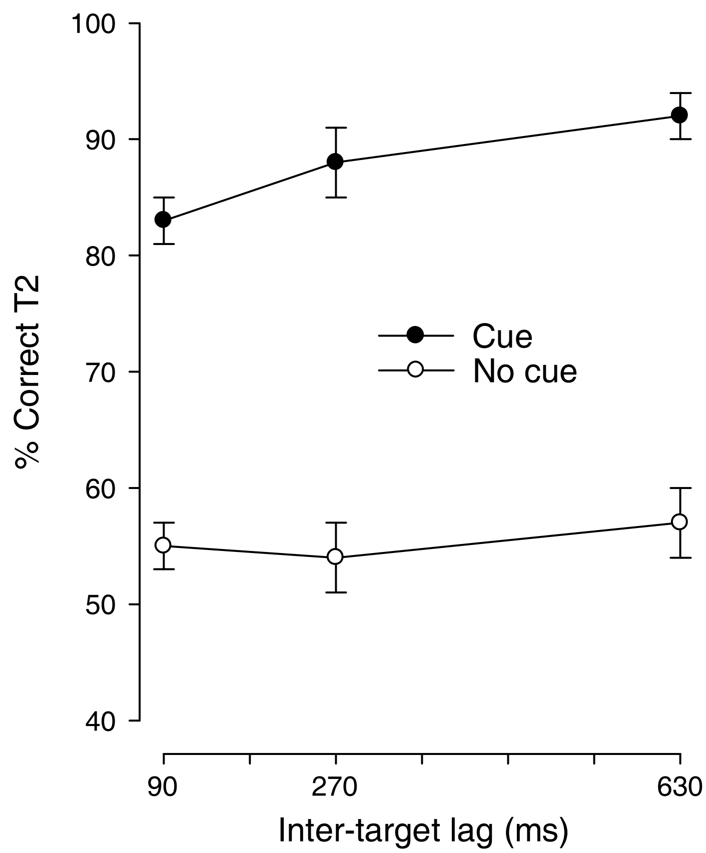

Figure 3. Results of Experiment 2. Bars represent the standard errors of the mean. T2: Second target; ms: milliseconds.

effect was not significant, $F(2, 22) = 1.90$, $p = 0.174$. As was the case in Experiment 1, the ANOVA was replicated on the log-transformed scores with essentially the same outcome: Cue, $F(1,11) = 85.31$, $p < 0.001$; Lag, $F(2,22) = 2.92$, $p = 0.075$; Cue × Lag, $F(2,22) = 1.10$, $p = 0.351$.

As expected, a stronger cueing effect was in evidence in Experiment 2 (compare Figures 2 and 3). On average, the second target was identified about 30% more accurately when its location was cued. Notably, the cue was equally effective whether it was presented during the period of the AB—when stimulus processing is expected to be impaired—or beyond that period. On the face of it, this pattern of results supports the additivity effect shown in Experiment 1. Before drawing a definitive conclusion, however, it is important to note that additivity is not simply the absence of a significant interaction (Sternberg, 1967). We are cautious in this conclusion because when we examined the simple effects of lag (i.e., within each cueing condition) there was no significant lag effect in the No cue condition. Indeed, accuracy in this condition was barely above the chance level of 50%. Therefore, in the next experiment, we removed the possibility of a floor effect in the No cue condition by using a procedure that was unconstrained by limitations imposed by the response scale.

Experiment 3

Experiment 3 used a dynamic threshold-seeking procedure called Parameter Estimation by Sequential Testing (PEST; Taylor & Creelman, 1967) to reduce the possibility of a floor effect in second-target accuracy. The exposure duration of the search array containing the second target was varied dynamically by PEST, separately for each observer, to converge on a level of 80% correct T2 responses. The dependent measure was the critical exposure duration (DUR_c) at which the observer obtained 80% correct responses. During the PEST procedure, the exposure duration of the second-target display (the search array) was varied dynamically, so that it was reduced when the observer's response accuracy exceeded the criterial level, and was increased when accuracy was too low. A Wald (1947) sequential likelihood ratio test determined whether the immediately preceding run of responses yielded an event proportion greater or less than 80%. The Wald end run that consisted of 16 trials after three reversals in the direction of adjustment of the exposure duration had been recorded. The DUR_c was the mean exposure duration over those last 16 trials; thus, DUR_c represents the duration of the mask-free interval after T2 onset that is necessary for achieving the criterial level of accuracy, separately for each observer. Twelve new observers served in Experiment 3. In all other respects, the methods were the same as in Experiment 2.

Results and discussion

The mean percentages of correct responses for the first target, averaged over lags, were 91.5% and 93.3% for the Cue and No cue conditions, respectively. The mean DUR_c values for the second target at each lag are illustrated in Figure 4. Note that since in this graph the dependent variable is DUR_c, lower values on the *Y*-axis indicate better performance. An ANOVA performed on the data in Figure 4 comprised two within-subjects factors: Cue (present, absent) and Lag (1, 3, 7). The analysis revealed significant effects of Cue, $F(1, 11) = 137.91$, $p < 0.001$, and Lag, $F(2, 22) = 6.87$, $p = 0.005$. The interaction effect was not significant, $F < 1$.

As seen in Figure 4, much shorter exposure durations (DUR_c) were required when the location of the second target was cued. In addition, as was the case in Experiment 2, a significant AB deficit was in evidence, with the values of DUR_c decreasing as Lag was increased. The important consideration for the objective of the present work is that the advantage conferred by the spatial cue was invariant with inter-target lag, and that the two lines in Figure 4 are parallel. This pattern of results replicates the outcome of Experiment 2 while avoiding the ambiguity caused by a possible floor effect. Considered

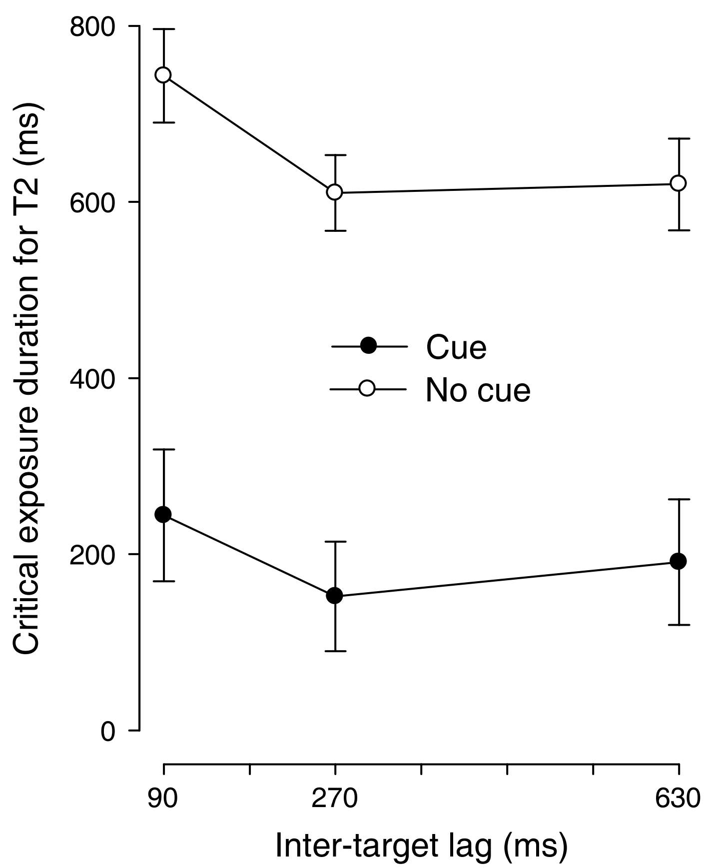

Figure 4. Results of Experiment 3. Bars represent the standard errors of the mean. T2: Second target; ms: milliseconds.

together, the outcomes of Experiments 1, 2, and 3 justify the conclusion that spatial selection and identity extraction are separable processes.

General discussion

The principal objective of the present work was to examine the separability of spatial selection and identity extraction processes in visual search by varying the two factors independently. This was done by combining two paradigms: spatial cueing and the AB within the same experiment. Spatial selection was manipulated by the presence or absence of a spatial cue directly before the second target. Identity extraction was manipulated by varying the temporal lag between the first and second targets.

In Experiment 1, the spatial cue was non-informative and the dependent measure was accuracy of second-target identification. Performance in the Valid cue condition was significantly more accurate than in the Invalid cue (or No cue) condition. Importantly, the difference in performance between the validly cued and invalidly cued (or uncued) conditions was invariant across inter-target lags. Based on additive-factors logic, this additivity was taken as evidence that spatial selection and identity extraction are separable factors in visual search. Experiment 2 examined the same hypothesis with a stronger (100% informative) cue. Again, there was no interaction between inter-target lag and cueing. A possible limitation of Experiment 2 arose from the finding that performance in the No cue condition was near a floor level imposed by the response scale. This was avoided in Experiment 3 by changing the dependent measure: instead of accuracy, we used a dynamic threshold-tracking procedure to find the critical exposure duration at which the second target could be identified on approximately 80% of the trials. The results were comparable to those of Experiment 2 in that there was no interaction between inter-target lag and cueing. In addition, the functions in the Cue and No cue conditions were completely parallel. Considered together, the outcomes of these three experiments support the conclusion that spatial selection and identity extraction are separable processes.

Comparison with related studies

Several recent studies have investigated the relationship between spatial cueing and the AB, although none of them was concerned explicitly with the separability of spatial and identity processes. Olivers (2004) investigated the effect of the AB on spatial processing in a study that, while addressing some of the issues in the present work, also differed from it in several ways. There were up to six simultaneous spatial cues, the SOA between the cue and the second target was considerably longer than in the present experiments (800 vs. 90 ms), and a pattern mask was presented directly after the cue display. The results showed that spatial processing was impaired during the AB but only when the number of cues was greater than one. In contrast, consistent with the present results, the interaction effect between cueing (cue present/absent) and the AB (inter-target lag short/long) was not significant when the display contained only one cue.[1] Thus, Olivers' conclusion of interdependence between spatial processing and the AB seems to apply only in the case of multiple cues. It is possible that the procedural differences between the two studies activated different mechanisms (e.g., spatial orienting vs. spatial memory) with consequent differences in the ways the search task was performed.

A study that perhaps comes closer to the present work has been reported by Nieuwenstein, Chun, van der Lubbe, and Hooge (2005, Experiment 4). In that experiment, a spatial cue was presented at the location of the second target 94 ms before target onset.

Consistent with the present findings, the cue was effective during the period of the AB. However, instead of being parallel as in the present study (e.g., Figures 2 and 3), the functions for the Cue and No cue conditions converged at the longer lag. The discrepancy between the two studies, however, has been ascribed to a procedural artifact in Nieuwenstein et al.'s study. Recent work in our laboratory has shown that the convergence of the two functions in Nieuwenstein et al.'s Experiment 4 arose from a data limitation ceiling, which prevented second-target accuracy from exceeding 70%, regardless of cueing. When the ceiling limitation was removed, the interaction disappeared, and the two functions became parallel, much as the functions obtained in all the present experiments (Ghorashi, Enns, Spalek, & Di Lollo, 2009).

Another study is of relevance to the present work, even though it did not employ spatial cues. Jiang and Chun (2001) employed flanker interference in an AB paradigm to examine the effects of spatial factors on second-target identification at short versus long inter-target lags. The results showed evidence of interdependence between spatial and identity processing. Namely, the perceptual interference caused by the flankers was more pronounced in the short-lag condition. On the face of it, this outcome contrasts with the present finding of separability. Jiang and Chun's results, however, could have been affected by much the same ceiling constraints as the study by Nieuwenstein et al. (2005). Namely, performance at the long inter-target lag was obviously compressed against a ceiling, causing the functions to converge thus producing an appearance of interdependence. The source of the performance ceiling differed in the two studies: data limitation (Nieuwenstein et al.) or upper limit of the response scale (Jiang & Chun). The consequence, however, was the same in that the ceiling constraint could have prevented parallel functions—and hence separability—from being in evidence.

A theoretical account

The separation of spatial cueing and identification processes in the present study is consistent with neuroanatomical and neurophysiological evidence for the dual system theory (Goodale & Milner, 2004; Milner & Goodale, 1995; Ungerleider & Mishkin, 1982). The two pathways originate in the retina and involve separate neuronal systems—the magnocellular (M) and the parvocellular (P)—that carry distinct types of information. The M neurons, characterized by relatively large receptive fields and fast conduction velocities, are insensitive to color but respond readily to movement and low-contrast stimuli. The P neurons are characterized by smaller receptive fields, are sensitive to color, and have slower conduction velocities.

These different response characteristics make the dorsal and ventral pathways suitable for processing different types of visual information. The idea of functional specialization was first realized by Ungerleider and Mishkin (1982) who referred to the two pathways as "Where" and "What" because space-related processes such as motion and depth perception were shown to be carried out along the dorsal stream, whereas object identification was shown to engage mainly the ventral stream. A similar distinction has been made by Milner and Goodale (1995) who preferred the term "How" to "Where". This is not to say that the two pathways are entirely independent from one another. Indeed, anatomical studies show the pathways are connected at every step along the way (Felleman & Van Essen, 1991; Van Essen & Anderson, 1995) and some imaging studies have reported that both pathways are involved in certain functions such as object identification (e.g., Konen & Kastner, 2008). However, none of this evidence rules out the possibility that the two pathways perform unique functions that can be isolated with appropriate experimental designs. For example, it is possible that the greatest separation occurs during the earliest (feedforward) stages of processing and that the interactions between streams emerge only in the later stages when feedback and horizontal connections become active. Such distinctions would be obscured by the low temporal resolution of present-day functional magnetic resonance imaging techniques.

We propose that the separability of the processes underlying spatial selection and identity extraction demonstrated in the present experiments can be mapped directly on the functional distinction between dorsal and ventral streams. Specifically, we suggest that the spatial cues used in the present experiments were processed mainly along the dorsal pathway and that the identification of the two letter targets was carried out principally along the ventral pathway. Within this conceptual framework, spatial selection and identity extraction are separable because they are mediated by mechanisms that are anatomically and functionally separable.

The functional distinction between the two pathways is also supported by clinical evidence from patients with damage to either visual pathway. For example, patients with optic ataxia (Bálint, 1909) typically have damage in the superior portion of the posterior parietal cortex (dorsal stream). Functionally, they are able to identify the nonspatial features of items without being able to successfully localize the positions of these features in space (Goodale, Milner, Jakobson, & Carey, 1991; Perenin & Vighetto, 1988). Conversely, other patients have been reported (Milner et al., 1991) who had damage to the ventrolateral regions of the occipital lobe or to the inferior temporal lobe (ventral stream). These patients usually show symptoms of visual agnosia in which they are unable to identify or describe attributes of visually presented objects, although they can use those objects in actions.

Similarly, behavioral studies with neurologically intact subjects have also provided hints that spatial selection and identity extraction may be separable functions. It has been shown, for instance, that while the identification of an object interferes with the planning of reaching for another object (a ventral pathway task), it does not interfere with the visually guided control necessary for completing the action (a dorsal pathway task; Liu, Chua, & Enns, 2008). In addition, there is evidence to support the occurrence of spatial selection without identity extraction for the target (Atkinson & Braddick, 1989; Ghorashi, Jefferies, Kawahara, & Watanabe, 2008).

There is also evidence for the separability of spatial selection and identity extraction in developmental studies. Trick and Enns (1998) have shown that voluntary movement of attention (spatial selection) and feature integration (identifying the target) have different trajectories over the life span. They displayed either a target that was defined by a single feature or a target that was defined by a conjunction of two features. They presented the target either as a single item in random locations or as a target among distractors. Results showed that feature binding reaches its asymptote at a relatively early age in life and then stays at that level, whereas voluntary movement of spatial attention follows a U-shaped pattern of performance across the life span. Namely, it matures at a later age than feature binding does and declines in senior adulthood.

On the tenability of null results

The main argument in the present study was predicated on additive-factors logic. On this logic, if two factors show additive effects, it is concluded that their underlying mechanisms are independent. By the same token, if two factors show interactive effects, it is concluded that they share at least some processing mechanisms. In experiments that reveal an additive relationship, a question might arise as to whether the inference of independence is tenable because it is based on a null result. With specific reference to the present work, a question might arise as to whether the absence of an interaction between the effects of cueing and inter-target lag reflects the independence of underlying mechanisms or a lack of power in the statistical analyses.

This concern can be addressed in three different ways that all converge on the same conclusion. The first approach is to note that the methods used in this series of experiments were also used in other works in our laboratory (Ghorashi, Enns et al., 2009; Ghorashi, Spalek, Enns, & Di Lollo, 2009) with similar pattern of results. That is, the results of the three experiments in the current work, the experiment in Ghorashi, Enns et al., and Experiment 2 in Ghorashi, Spalek et al., all indicated main effects of both of the two main factors that were manipulated, with an additive pattern of these effects when they were combined (no hint of statistically significant interactions), pointing consistently to the separability of spatial selection and identity extraction. Thus, the evidence for additivity in the experiments considered collectively satisfy the minimal requirement for science, namely, that of replication.

Examining the issue of replication in more detail, it is extremely unlikely on the basis of conventional statistical reasoning that this result would reoccur in all five experiments mentioned above. In fact, if the α level is increased from 0.05 to 0.5 in order to decrease the probability of a type II error to an extremely low level (and thus increase the power of the test to detect a possible interaction), in four of five experiments the interaction would still be non-significant. The only experiment in which an α level of 0.5 would indicate a significant interaction would be Experiment 2 (present work) in which there was a chance of a floor effect, preventing a full additive pattern from being in evidence. Table 1 presents the η^2 calculated for each experiment that showed an additive pattern and the post-hoc calculated power of each test for detecting a moderate (0.4) effect, using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), in each experiment.

The second approach is the one taken by Sternberg (1969) in his original development of the methodology. Noting that the absence of a statistical interaction in the additive patterns constituted a null result, Sternberg (1969, p. 287) said: "Experimental artifacts are more likely to obscure true additivity of factor effects than true interactions". In short, his argument was that random factors alone were much less likely to generate an additive pattern (one highly specific pattern) than they were to generate an interactive pattern (any one of which would violate the assumption of additivity). Seeing this pattern occur repeatedly in the different experiments stretches the credulity that this could have occurred solely through chance factors.

Experiment	η^2	Power
1 (Current article)	0.057	0.88
2 (Current article)	0.147	0.88
3 (Current article)	0.046	0.88
Ghorashi, Enns et al. (2009)	0.001	0.99
Experiment 2 in Ghorashi, Spalek et al. (2009)	0.016	0.99

Table 1. Calculated partial effect size (η^2) and power for detecting a moderate effect (0.4) for each experiment in which an additive effect was evident in the current article as well as in Ghorashi, Enns et al. (2009) and Ghorashi, Spalek et al. (2009).

Finally, the F ratios for the interaction effects in four of the five experiments were <1. This means that, on a post-hoc analysis based on the present pattern of results, and on the assumption that the F ratio remains approximately the same, such an F ratio would not be significant even if the number of subjects (the *degrees of freedom* for the denominator of the F ratio) were unlimited. This would also be the case for the F ratio of 1.9 obtained in Experiment 2 (current article), since this value is smaller than the critical F-value against which 1.9 would be compared given an infinite number of subjects [$F_{\text{critical}}(2,\infty) = 3.00$].

On the strength of these three arguments, we are confident that the present experiments did not lack the necessary power and, therefore, that additive-factors logic was used appropriately to conclude in favor of real independence between the processes of spatial selection and identity extraction.

Concluding comments

Two further issue need to be raised regarding the separability of location and identity processes. First, earlier work has shown that visual search is postponed during the AB (Ghorashi, Smilek, & Di Lollo, 2007). In light of the present result that spatial cueing is unimpaired during the AB, it is plausible to assume that what is postponed during the AB is the process of second-target identification, not the process of orienting spatial attention from one location to another.

Second, the cueing processes involved in the present experiments were, initially at least, stimulus driven, engaging principally the dorsal pathway. Within the conceptual framework outlined above, it should be expected that, were the cue to require processing along the ventral pathway, separability would no longer be in evidence. This is because both the cue and the targets would require access to the same processing mechanisms. Evidence consistent with this expectation has been reported by Dell'Acqua, Sessa, Jolicœur, and Robitaille (2006). In that study, the first target was a pair of digits to be identified (a ventral stream task), and the second-target task involved spatial selection based on color (also a ventral stream task). Consistent with the present theoretical conviction, Dell'Acqua et al. (2006) reported that spatial selection was impaired during the AB. Further evidence for this view was recently provided by a recent AB study of our own (Ghorashi, Spalek et al., 2009) in which second-target location was specified either by a cue that did not require ventral processing (location-based cuing) or by one that did (shape-based cuing). First and second-target accuracies interacted only with the shape-based cue, consistent with our proposal that spatial orienting and target identification are independent visual functions.

Acknowledgments

This research was supported by individual Discovery Research Grants from the Natural Sciences and Engineering Research Council (Canada) to V. Di Lollo, J. T. Enns, and R. M. Klein.

Commercial relationships: none.
Corresponding author: Shahab Ghorashi.
Email: shahab.ghorashi@gmail.com.
Address: VA Boston Healthcare System, Research 151C, 150 S. Huntington Avenue, Boston, MA 02130, USA.

Footnote

[1]We thank Christian N. L. Olivers for providing this additional information.

References

Atkinson, J., & Braddick, O. J. (1989). "Where" and "what" in visual search. *Perception, 18,* 181–189. [PubMed]

Bálint, R. (1909). Seelenlähmung des Schauens, optische Ataxie, räumliche Störung der Aufmerksamkeit. *Monatzeitschrift für Psychiatrie und Neurologie, 25,* 51–81.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in RSVP. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 109–127. [PubMed]

Colegate, R. L., Hoffman, J. E., & Eriksen, C. W. (1973). Selective encoding from multielement visual displays. *Perception & Psychophysics, 14,* 217–224.

Dell'Acqua, R., Sessa, P., Jolicœur, P., & Robitaille, N. (2006). Spatial attention freezes during the attentional blink. *Psychophysiology, 43,* 394–400. [PubMed]

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

Dux, P. E., & Marois, R. (2009). The attentional blink: A review of data and theory. *Attention, Perception & Psychophysics, 71,* 1683–1700. [PubMed]

Eckstein, M. P. (1998). The lower visual search efficiency for conjunctions is due to noise and not serial attentional processing. *Psychological Science, 9,* 111–118.

Eriksen, C. W., & Hoffman, J. E. (1972). Temporal and spatial characteristics of selective encoding from visual displays. *Perception & Psychophysics, 12,* 201–204.

Eriksen, C. W., & Yeh, Y.-Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 583–597. [PubMed]

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39,* 175–191. [PubMed]

Felleman, D. J., & Van Essen, D. C. (1991). Distributed hierarchical processing in the primate cerebral cortex. *Cerebral Cortex, 1,* 1–47. [PubMed]

Ghorashi, S., Enns, J. T., Spalek, T. M., & Di Lollo, V. (2009). Spatial cueing does not affect the magnitude of the attentional blink. *Attention, Perception & Psychophysics, 71,* 989–993. [PubMed]

Ghorashi, S., Spalek, T. M., Enns, J. T., & Di Lollo, V. (2009). Are spatial selection and identity extraction separable when attention is controlled endogenously? *Attention, Perception & Psychophysics, 71,* 1233–1240. [PubMed]

Ghorashi, S. M. S., Di Lollo, V., & Klein, R. M. (2007). Attentional orienting in response to peripheral cues survive the attentional blink. *Visual Cognition, 15,* 87–90.

Ghorashi, S. M. S., Jefferies, L. N., Kawahara, J., & Watanabe, K. (2008). Does attention accompany the conscious awareness of both location and identity of an object? *Psyche, 14*. Available online at http://journalpsyche.org/ojs-2.2/index.php/psyche/article/viewFile/2317/2257.

Ghorashi, S. M. S., Smilek, D., & Di Lollo, V. (2007). Visual search is postponed during the attentional blink until the system is suitably reconfigured. *Journal of Experimental Psychology: Human Perception and Performance, 33,* 124–136. [PubMed]

Goodale, M. A., & Milner, A. D. (2004). Plans for action. *Behavioral & Brain Sciences, 27,* 37–40.

Goodale, M. A., Milner, A. D., Jakobson, L. S., & Carey, D. P. (1991). A neurological dissociation between perceiving objects and grasping them. *Nature, 349,* 154–156. [PubMed]

Green, M. (1991). Visual search, visual streams, and visual architectures. *Perception & Psychophysics, 50,* 388–403. [PubMed]

Green, M. (1992). Visual search: Detection, identification, and localization. *Perception, 21,* 765–777. [PubMed]

Jiang, Y. H., & Chun, M. M. (2001). The influence of temporal selection on spatial selection and distractor interference: An attentional blink study. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 664–679. [PubMed]

Jolicœur, P., & Dell'Acqua, R. (1998). The demonstration of short-term consolidation. *Cognitive Psychology, 36,* 138–202. [PubMed]

Jonides, J. (1980). Towards a model of the mind's eye's movement. *Canadian Journal of Psychology, 34,* 103–112. [PubMed]

Julesz, B. (1984). A brief outline of the texton theory of human vision. *Trends in Neuroscience, 7,* 41–45.

Klein, R. M. (2004). On the control of orienting. In M. I. Posner (Ed.), *Cognitive neuroscience of attention* (pp. 29–44). New York: Guilford Press.

Konen, C. S., & Kastner, S. (2008). Two hierarchically organized neural systems for object information in human visual cortex. *Nature Neuroscience, 11,* 224–231. [PubMed]

Liu, G., Chua, R., & Enns, J. T. (2008). Attention for perception and action: Task interference for action planning, but not for online control. *Experimental Brain Research, 185,* 709–717. [PubMed]

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. London, UK: Oxford University Press.

Milner, A. D., Perrett, D. I., Johnston, R. S., Benson, P. J., Jordan, T. R., Heeley, D. W., et al. (1991). Perception and action in 'visual form agnosia'. *Brain, 114,* 405–428. [PubMed]

Nieuwenstein, M. R., Chun, M. M., van der Lubbe, R. H. J., & Hooge, I. T. C. (2005). Delayed attentional engagement in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 1463–1475. [PubMed]

Olivers, C. N. L. (2004). Blink and shrink: The effect of the attentional blink on spatial processing. *Journal of Experimental Psychology: Human Perception and Performance, 30,* 613–631. [PubMed]

Palmer, J. (1995). Attention in visual search: Distinguishing four causes of a set-size effect. *Current Directions in Psychological Science, 4,* 118–123.

Perenin, M.-T., & Vighetto, A. (1988). Optic ataxia: A specific disruption in visuomotor mechanisms. *Brain, 111,* 643–674. [PubMed]

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32,* 3–25. [PubMed]

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18,* 849–860. [PubMed]

Sagi, D., & Julesz, B. (1985a). Detection versus discrimination of visual orientation. *Perception, 14,* 619–628. [PubMed]

Sagi, D., & Julesz, B. (1985b). "Where" and "what" in vision. *Science, 228,* 1217–1219. [PubMed]

Schweickert, R. (1985). Separable effects of factors on speed and accuracy: Memory scanning, lexical decision, and choice tasks. *Psychological Bulletin, 97,* 530–546. [PubMed]

Sternberg, S. (1967). Two operations in character-recognition: Some evidence from reaction-time measurements. *Perception & Psychophysics, 2,* 45–53.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donder's method. In W. G. Koster (Ed.), *Attention and performance II* (pp. 276–315). Amsterdam, The Netherlands: North-Holland.

Taylor, M. M., & Creelman, C. D. (1967). PEST: Efficient estimates on probability functions. *Journal of the Acoustical Society of America, 41,* 782–787.

Treisman, A. (1988). Features and objects: The fourteenth Bartlett memorial lecture. *Quarterly Journal of Experimental Psychology, 40A,* 201–237. [PubMed]

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12,* 97–136. [PubMed]

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. *Psychological Review, 95,* 15–48. [PubMed]

Treisman, A., & Sato, S. (1990). Conjunction search revisited. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 459–478. [PubMed]

Trick, L. M., & Enns, J. T. (1998). Lifespan changes in attention: The visual search task. *Cognitive Development, 13,* 369–386.

Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 549–586). Cambridge, MA: MIT Press.

Van Essen, D. C., & Anderson, C. H. (1995). Information processing strategies and pathways in the primate visual system. In Zornetzer et al. (Eds.), *An introduction to neural and electronic networks* (2nd ed., pp. 45–76). San Diego: Academic Press.

Wald, A. (1947). *Sequential analysis*. New York: Wiley.

Wolfe, J. M. (1994). Guided Search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review, 1,* 202–238.

Wolfe, J. M. (2006). Guided Search 4.0: Current Progress with a model of visual search. In W. Gray (Ed.), *Integrated models of cognitive systems* (pp. 99–119) New York: Oxford.