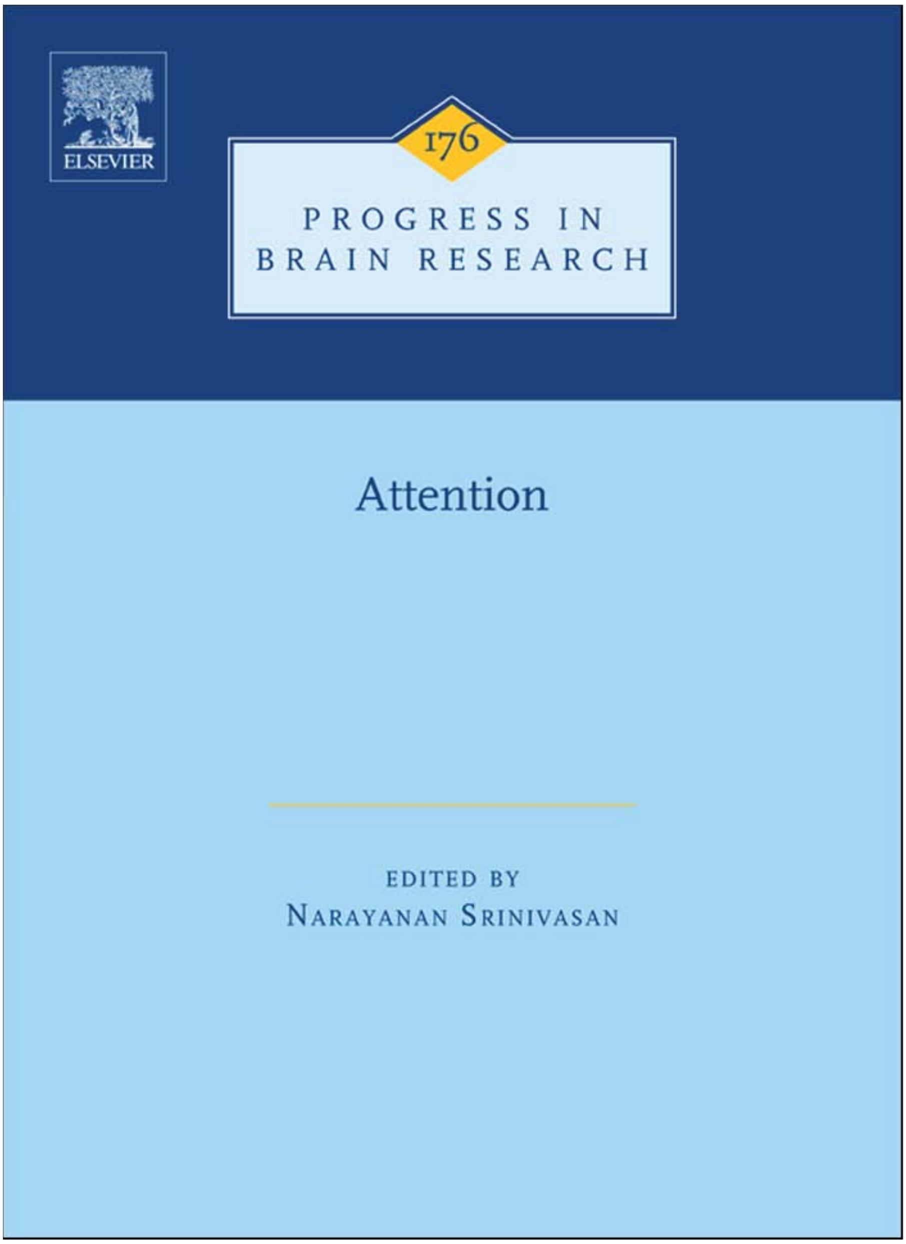

From Ruth Kimchi, Perceptual organization and visual attention. In: Narayanan Srinivasan, editor:
Progress in Brain Research, Vol 176, Narayanan Srinivasan.
The Netherlands: Elsevier, 2009, pp. 15–33.
ISBN: 978-0-444-53426-2

N. Srinivasan (Ed.)
Progress in Brain Research, Vol. 176
ISSN 0079-6123

CHAPTER 2

Perceptual organization and visual attention

Ruth Kimchi*

Department of Psychology & Institute of Information Processing and Decision Making, University of Haifa, Haifa, Israel

Abstract: Perceptual organization — the processes structuring visual information into coherent units — and visual attention — the processes by which some visual information in a scene is selected — are crucial for the perception of our visual environment and to visuomotor behavior. Recent research points to important relations between attentional and organizational processes. Several studies demonstrated that perceptual organization constrains attentional selectivity, and other studies suggest that attention can also constrain perceptual organization. In this chapter I focus on two aspects of the relationship between perceptual organization and attention. The first addresses the question of whether or not perceptual organization can take place without attention. I present findings demonstrating that some forms of grouping and figure-ground segmentation can occur without attention, whereas others require controlled attentional processing, depending on the processes involved and the conditions prevailing for each process. These findings challenge the traditional view, which assumes that perceptual organization is a unitary entity that operates preattentively. The second issue addresses the question of whether perceptual organization can affect the automatic deployment of attention. I present findings showing that the mere organization of some elements in the visual field by Gestalt factors into a coherent perceptual unit (an "object"), with no abrupt onset or any other unique transient, can capture attention automatically in a stimulus-driven manner. Taken together, the findings discussed in this chapter demonstrate the multifaceted, interactive relations between perceptual organization and visual attention.

Keywords: perceptual organization; visual attention; grouping; figure-ground segmentation; attentional capture; inattention

Introduction

Perceptual organization and visual attention are crucial for the perception of our visual environment and to visuomotor behavior. Perceptual organization refers to the visual processes structuring the bits and pieces of visual information into coherent units that we eventually experience as environmental objects. The Gestalt psychologists, who were the first to study perceptual organization, suggested that organization is composed of grouping and segregation processes (Koffka, 1935), and identified several stimulus factors that determine organization. These include grouping factors such as proximity, similarity, good continuation, common fate, and closure (Wertheimer, 1955/1923), and factors that govern figure-ground organization, such as size, contrast, convexity, and symmetry (Rubin, 1921). Recently, researchers have identified additional factors that support grouping — common region

*Corresponding author.
Tel.: +972-4-8249746; Fax: +972-4-8249431;
E-mail: rkimchi@research.haifa.ac.il

DOI: 10.1016/S0079-6123(09)17602-1

(Palmer, 1992) and element connectedness (Palmer and Rock, 1994) — and figure-ground assignment — familiarity (Peterson and Gibson, 1994), lower region (Vecera et al., 2002), spatial frequency (Klymenko and Weisstein, 1986), base width (Hulleman and Humphreys, 2004), and extremal edges (Palmer and Ghose, 2008).

Visual attention refers to the processes by which some visual information in a scene is selected, in particular, information that is most relevant to ongoing behavior. Deployment of attention can be goal-directed, based on current behavioral goals of the observer (e.g., Desimone and Duncan, 1995; Posner, 1980). If we know, for example, where is the most probable target location we can use this information to voluntarily (endogenously) direct our attention to this location. Deployment of attention can also be stimulus-driven. In this case, attention is captured involuntarily (exogenously) by certain stimulus events, such as an abrupt onset of a new perceptual object and some types of simple luminance and motion transients (e.g., Abrams and Christ, 2003; Jonides, 1981; Yantis and Hillstrom, 1994), or a salient singleton (e.g., Theeuwes et al., 2003, but see Folk et al., 1992).

Recent research has demonstrated a close interplay between attentional and perceptual organization processes (e.g., Driver et al., 2001; Scholl, 2001). Several studies demonstrated that perceptual organization constrains attentional selectivity. For example, interference from distractor stimuli in selective attention tasks is greater when the target and distractors are strongly grouped by Gestalt cues such as color similarity, good continuation, closure, or common fate (e.g., Baylis and Driver, 1992; Driver and Baylis, 1989; Kahneman and Henik, 1981; Kramer and Jacobson, 1991), and responding to two features is easier when they belong to the same object than when they belong to two separate objects (e.g., Behrmann et al., 1998; Duncan, 1984; Lavie and Driver, 1996; Vecera and Farah, 1994). Also, the cost incurred during target detection when attention is initially cued to a non-target location is smaller for targets that appear in the same object as the cue than for targets appearing in a different object, despite their equivalent distance from the cued location (e.g., Egly et al., 1994; Moore et al., 1998). In addition, neurophysiological studies have found that attended stimuli and unattended stimuli belonging to the same object elicited a very similar spatiotemporal pattern of enhanced neural activity in the visual cortex, even when the objects were defined by illusory boundaries (Martinez et al., 2006, 2007).

Other studies suggest that attention can also constrain perceptual organization. For example, Freeman et al. (2001, 2004) provided evidence for influence of attention on flanker-target integration, demonstrating that detection of a central Gabor target was improved by the presence of collinear flankers when the collinear flankers were attended, but not when the collinear flankers were ignored in favor of flankers with orthogonal orientation. Attention can also influence figure-ground organization (e.g., Peterson and Gibson, 1994; Vecera et al., 2004). For example, Vecera and colleagues demonstrated that when spatial attention is directed to one of the regions of an ambiguous figure-ground stimulus, the attended region is perceived as figure and the shared contour is assigned to the attended region.

These various findings suggest that perceptual organization and visual attention mutually constrain one another.

In this chapter I focus on two issues concerning the relationships between visual attention and perceptual organization. The first focuses on the question of whether or not perceptual organization can be accomplished without attention. The second issue concerns the question of whether perceptual organization can affect the automatic deployment of attention.

Can perceptual organization occur without attention?

Traditional theories of perception assumed that perceptual organization, including grouping and figure-ground segmentation, occurs preattentively, at an early stage of processing and in a bottom-up fashion, to deliver the units for which attention can be allocated for further, more elaborated processing (e.g., Julesz, 1981; Marr, 1982; Neisser, 1967; Treisman, 1982, 1988). Thus, for example, Treisman (1982, p. 195) noted that ‘‘the theories all agree that perceptual grouping occurs automatically and in parallel, without attention.’’ This assumption was based on logical considerations and supported by some empirical findings. Prima facie, if attention is to select candidate objects, then some organization of the visual scene into these objects must occur prior to selection. Empirical findings that were interpreted as supporting this view came from texture segregation and visual search studies showing that certain texture boundaries and certain items ‘‘pop-out’’ under very brief exposures and without effort and scrutiny (e.g., Beck, 1982; Julesz, 1981; Treisman, 1982, 1985), from dual-task studies demonstrating successful texture segregation even though visual attention is engaged with a demanding primary task (e.g., Braun and Sagi, 1990, 1991), and from studies showing that segmentation of the visual field into perceptual groups on the basis of Gestalt principles constrains attentional selectivity (e.g., Baylis and Driver, 1992; Driver and Baylis, 1989; Duncan, 1984; Vecera and Farah, 1994).

An alternative view suggests that no, or very little, perceptual organization can take place without attention (Ben Av et al., 1992; Mack et al., 1992; Mack and Rock, 1998; Palmer and Rock, 1994; Rock et al., 1992). For example, Ben Av et al. (1992) showed that when participants performed a demanding central form identification task and also had to report whether background elements grouped into horizontal or vertical pattern on the basis of proximity or similarity, grouping performance was severely reduced (relative to single-task situation), suggesting that perceptual grouping requires visual attention.

The main support for this view came from the work of Mack and Rock, and their colleagues (Mack et al., 1992; Mack and Rock, 1998; Rock et al., 1992). Mack and Rock argued, and rightfully so, that none of the findings taken as evidence for preattentive perceptual organization were obtained under conditions in which information was truly unattended. Rather, these findings pertain to diffuse or divided attention conditions, in which participants are aware of the potential relevance of the information in the visual scene, including information outside the focus of attention. For example, the secondary-task information in a dual-task procedure is task relevant, and in visual search participants actively search for a predefined target while ignoring distracting information. Similarly, in all the studies examining object-based attentional selection, at least part of the relevant object is attended, and this may cause other parts of the object also to be attended. In contrast, the *inattention method* developed by Mack and Rock attempted to tap processing of unattended stimuli under conditions in which participants are engaged in a highly demanding visual task, and the unattended stimuli are completely irrelevant to the task at hand, so that participants have no reason whatsoever to attend to them.

Grouping under inattention

Mack et al. (1992) used the inattention method to examine whether perceptual grouping can take place under inattention. Participants performed a demanding discrimination task — determining whether the horizontal or vertical line of a centrally, briefly presented cross is longer. In the first few trials the cross was surrounded by ungrouped small elements. On the fourth, *inattention trial*, the surrounding elements were grouped into rows or columns by proximity or lightness similarity, and the participants were asked, after completing the length judgment, about the background organization. Participants were ‘‘inattentionally blind’’ to the grouping of the background elements — they could not report whether the background organization was vertical or horizontal. In a subsequent attention trial, in which participants attended to the background elements, these patterns were easily reported. These kinds of findings led Mack and Rock (Mack et al., 1992; Mack and Rock, 1998) to the conclusion that no Gestalt grouping takes place without attention.

However, Mack and Rock’s work was criticized on the ground that poor knowledge of the background organization may reflect poor explicit memory, rather than indicating that no grouping took place when the unattended stimuli were presented. To circumvent the issue of explicit memory, Moore and Egeth (1997) used the inattention paradigm but devised indirect online measures of unattended processing by examining the influence of the unattended information on responses to the attended information. Participants were required to determine which of two horizontal lines is longer. On the inattention trial the elements in the background were grouped by luminance into inducers biasing the length of the horizontal lines by creating Muller-Lyer or Ponzo illusion. Participants were unable to report the background organization, but their line length judgments were influenced by the illusions. These findings suggest that grouping by similarity in luminance occurs under conditions of inattention, albeit without participants' awareness (see also, Lamy et al., 2006). Similar results were found when background elements were grouped by similarity in size (Chan and Chua, 2003).

The method developed by Russell and Driver (2005; originally described in Driver et al., 2001) also provides indirect online measures of unattended processing. On each trial, two successive displays were presented, each of which included a small, centrally located matrix (made up of random black and white pixels) surrounded by task-irrelevant background elements grouped by color similarity into rows or columns, or randomly organized. The task was to judge whether the matrices in the two successive displays were the same or different. When the matrices differed, only one pixel changed its location, rendering the task sufficiently demanding to absorb attention. The background organization stayed the same or changed across the two displays, independently of whether or not the target matrix changed. The results showed that grouping of the background stimuli — whether it stayed the same or changed across successive displays — influenced the detection of changes in the target matrix, even though when probed with surprise questions, participants reported no or little awareness of the background grouping or its changes. These findings suggest that the unattended background elements were perceptually grouped.

Recently, Shomstein et al. (2009) reported similar results in a situation in which the definition of "unattended" did not rely on participants self-report of lack of awareness of the background grouping. They adapted Russell and Driver's (2005) method to test individuals with hemispatial neglect. In their study, patients (and matched controls) performed the target change-detection task on a matrix presented entirely to their intact side of space, and the task-irrelevant grouped elements (columns and rows by color similarity) appeared simultaneously on the unattended side. Changes in the grouping of the neglected task-irrelevant elements produced congruency effects on the target change judgments to the same extent as in the control participants even in patients with severe attentional deficits, suggesting that the grouping was accomplished in the absence of attention.

Figure-ground segmentation under inattention

The view that figure-ground segmentation operates preattentively has been widely accepted, but the evidence is scant (e.g., Driver et al., 1992) and open to alternative interpretations, particularly in light of recent research indicating that exogenous attention can influence figure-ground assignment (Vecera et al., 2004), and that figural cues per se can possibly attract attention (Nelson and Palmer, 2007).

To examine whether figure-ground segmentation can take place without attention, Mary Peterson and I (Kimchi and Peterson, 2008) adapted Russell and Driver's (2005) inattention method. In our study, the target matrix appeared on a task-irrelevant scene of alternating regions organized into figures and grounds by convexity (see Figs. 1a–d). The backdrop region on which the matrix appeared could be convex (figure) or concave (ground). On each trial two successive displays were briefly presented and the task was to judge whether the central matrices are the same or different. The figure-ground organization of the scene backdrop stayed the same or changed across the two successive displays, independently of whether or not the target matrix changed. The edges in the backdrop always changed from the first to the second display regardless of whether or not the figure-ground organization changed, to control for the possibility that a change in backdrop organization could be detected from local changes in edges per se. An example of the display sequence in a single experimental trial is

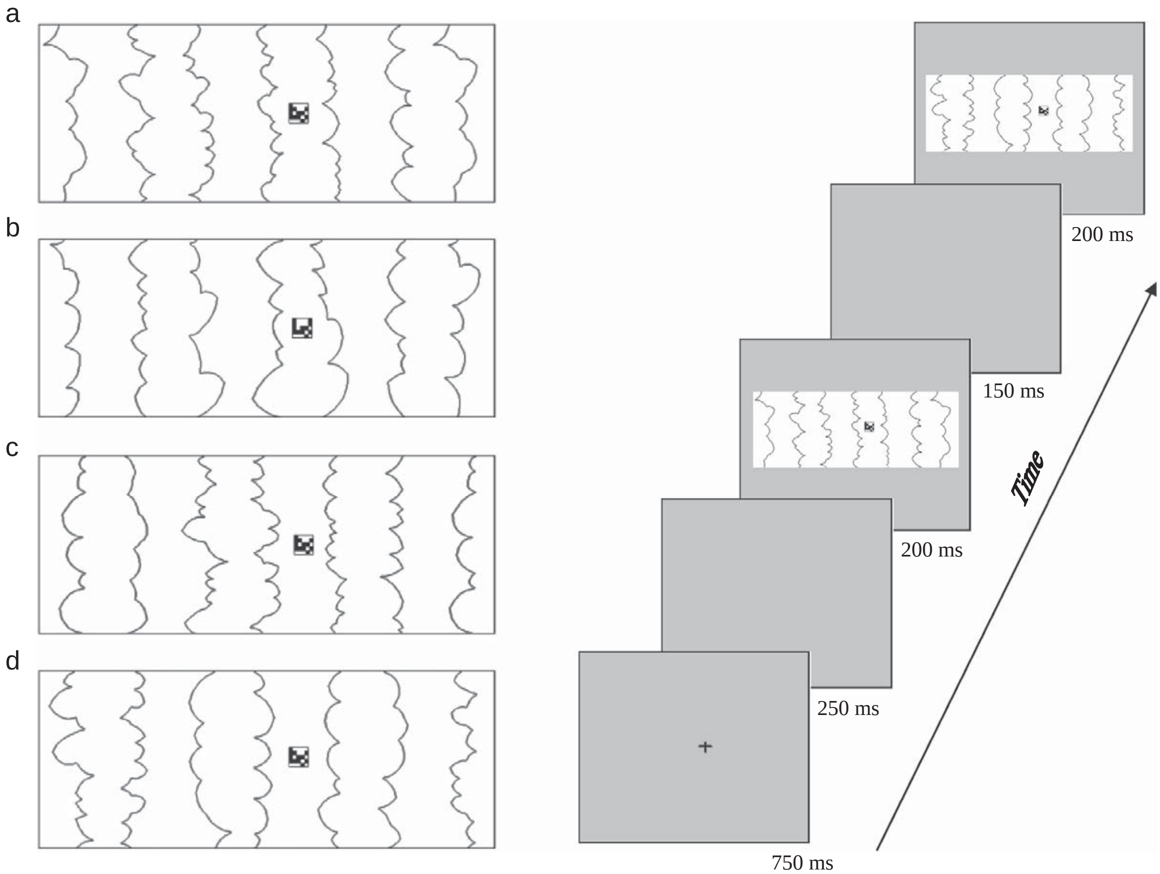

Fig. 1. Left panel: Examples of the displays used by Kimchi and Peterson (2008). In the experiments, displays were presented on a gray field, and no frame was used. The target matrix always appeared on the backdrop region to the right of the central edge (i.e., the fifth region from the left). This region could be convex (figure, F) or concave (ground, G), and the number of parts in this region could be small or large. The examples illustrate (a) the F type with a large part number, (b) the F type with a small part number, (c) the G type with a large part number, and (d) the G type with a small part number. The matrices in (a) and (b) depict an example of a change in matrix (a change in the location of one small black square). Right panel: Sequence of events in a trial. Two successive displays were presented on each trial. The target matrix in successive displays could stay the same or change. The backdrop organization across successive displays could stay the same (FF or GG) or change (FG or GF), independently of whether the target matrix changed or remained the same. The edges in the backdrop always changed from the first to the second display (a backdrop with a small number of parts was paired with a backdrop with a large number of parts). The illustration depicts a same-target trial (matrix is unchanged) on a backdrop that changes from figure to ground. Adapted with permission from Kimchi and Peterson (2008).

presented in Fig. 1, right panel. We examined whether the figure-ground organization of the scene backdrop influenced performance on the matrix-change task. After the last experimental trial, observers were probed with surprise questions asking whether the region on which the target was presented in the preceding display appeared to be figure or ground and whether the figure-ground status of that region had changed between the two displays on that trial.

The main results are presented in Fig. 2. Changes in the scene backdrop's figure-ground organization produced reliable congruency effects on target-change judgments: Target-different judgments were more efficient when backdrop organization changed across the two displays than when it remained the same, and target-same judgments were more efficient when backdrop organization stayed the same than when it changed. These results could not be due to the backdrop's changes in

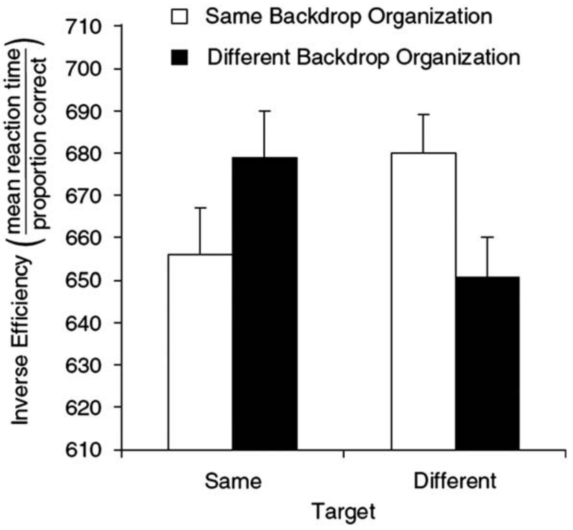

Fig. 2. Results from Kimchi and Peterson (2008). Inverse-efficiency scores for same and different targets as a function of the backdrop's organization (same, different). Error bars indicate standard errors of the means. Adapted with permission from Kimchi and Peterson (2008).

convexity/concavity per se. Performance was less efficient on trials where the backdrop region on which the matrix appeared changed from ground (concave) to figure (convex) — a new figure (a ‘‘new object'') appeared in the target's backdrop region — than on trials where the backdrop region changed from figure to ground (no new figure in this region). Presumably, implicit processing of a new figure on the former produced less efficient responses to the target. Changes in convexity/concavity per se would not predict a difference between these two types of trials, because in both types convex and concave regions changed their location across successive displays. The congruency effects produced by changes in the backdrop figure-ground organization arose even though, when probed with surprise questions, participants could report neither the figure-ground status of the region on which the matrix appeared nor any change in that status. When attending to this region, participants reported its figure-ground status and changes to it highly accurately. These results strongly suggest that some figure-ground segmentation can occur without attention.

Taken together, the findings reviewed in the last two sections suggest that some forms of perceptual grouping and figure-ground segmentation take place under inattention. In the following section I present findings suggesting that perceptual organization processes vary in their attentional demands.

Perceptual organization and attention: not all organizations are equal

Implicit in traditional theories of perception is the assumption that perceptual organization is a unitary entity. A growing body of research, however, has challenged this monolithic view (e.g., Behrmann and Kimchi, 2003; Ben Av and Sagi, 1995; Hadad and Kimchi, 2006; Han, 2004; Kimchi, 1988, 2000; Kimchi et al., 2005; Kimchi and Razpurker Apfeld, 2004; Kovacs et al., 1999; Kurylo, 1997; Quinn and Bhatt, 2006; Razpurker Apfeld and Kimchi, 2007). For example, several studies showed that groupings guided by different Gestalt principles vary in their time course and developmental trajectory. Experiments with adults showed that grouping by proximity is achieved faster than grouping by similarity in luminance or in shape (Ben Av and Sagi, 1995; Han, 2004) and faster than grouping by good continuation (Kurylo, 1997). Infant studies showed that grouping by common lightness is evident in 3-month-olds (Quinn et al., 1993, 2002), but only 6- to 7-month-olds readily use grouping by shape similarity (Quinn et al., 2002; Quinn and Bhatt, 2006). Sensitivity to good continuation has been documented in 3- to 4-month-old infants (Quinn and Bhatt, 2005), but the ability to group line segments by good continuation appears to be highly constrained by proximity between the segments even at 5 years of age (Hadad and Kimchi, 2006; Kovacs et al., 1999). Also, Kimchi (1998) showed that the global configuration of many small elements was primed at brief exposures and accessible to rapid search, suggesting rapid and effortless grouping, whereas the global configuration of a few relatively large elements was primed at longer exposures and searched inefficiently, suggesting time-consuming and attention-demanding grouping. The former grouping is mature by age 5, whereas the latter improves with age, primarily between ages 5 and 10 (Kimchi et al., 2005).

In addition to noting that grouping involves various principles that may differ from each other, it has been suggested that grouping itself may not be a single process, but rather involves two distinct processes: a process of unit formation or clustering that determines which elements belong together and are segregated from other elements, and a process of shape formation or configuring that determines how the grouped elements appear as a whole based on the interrelations of the elements (Koffka, 1935; Rock, 1986; Trick and Enns, 1997). Trick and Enns (1997) found that enumeration of hierarchical figures — presumably requiring just clustering of local elements — was identical to that of connected figures with both exhibiting equal subitizing, but when the figures were enumerated among distractors — thus involving shape discrimination — only the connected figures were subitized. Trick and Enns interpreted these results as indicating that shape formation requires attention whereas clustering does not. Other studies provide some hints for a continuum of attentional demands rather than a dichotomy (e.g., Behrmann and Kimchi, 2003; Han and Humphreys, 1999; Han et al., 1999). For example, Behrmann and Kimchi (2003) studied perceptual organization in two patients suffering from integrative agnosia. Both patients had no problem grouping elements into columns/rows by proximity or by luminance similarity, but they exhibited different degrees of difficulty grouping elements into a global shape.

To directly examine whether different groupings vary in their attentional demands, Irene Razpuker-Apfeld and I (Kimchi and Razpurker Apfeld, 2004) used Russell and Driver's (2005; Driver et al., 2001) method and manipulated the unattended grouping.

We employed different background organizations (examples of which are presented in Fig. 3), which vary in the processes involved in the grouping. The critical organizations were grouping of columns/rows by color similarity (Fig. 3A), grouping of shape (square/cross or triangle/arrow) by color similarity (Fig. 3B), and grouping of shape (square/cross or triangle/arrow) of homogeneous elements (Fig. 3C). The first two groupings involve elements clustering and segregation (by color similarity) and shape formation. Shape formation, however, may be less demanding for the columns/rows — requiring determination of the orientation (vertical or horizontal) of the grouped pattern, than for the shape by color similarity — requiring the formation of a distinctive shape (Rock, 1986). The third grouping involves clustering and shape formation but no elements segregation; therefore it may be less demanding than the grouping of shape by color similarity. (Additional organizations were connected triangle/arrow and square/cross made of disconnected lines.) On each trial two successive displays were briefly presented and the task was to judge whether the central matrices are the same or different. The background stayed the same or changed across successive displays independently of any change in the target matrix. After the last experimental trial, observers were probed with surprise questions about the immediately preceding background displays.

The results for the critical organizations are presented in Fig. 4 (the results for the triangle/arrows paralleled those for the square/cross). Influence of the background organization on the target-change judgments was observed for grouping of columns/rows by color similarity (Fig. 4A): Target-same judgments were faster when the background stayed the same than when it changed, and target-different judgments were faster when the background organization changed than when it stayed the same, and for grouping of shape when no elements segregation was involved (Fig. 4C): Target-same judgments were faster and more accurate when the background stayed the same, and target-different judgments were more accurate when the background organization changed. No influence of the background organization was found for grouping of shape by color similarity (Fig. 4B). For all three conditions, participants were unable to report the background organization of the immediately preceding background displays.

The difference between the results for the columns/rows and for the shape by common color is of particular interest because both groupings were guided by the same principle of similarity in color, but nevertheless the former took place

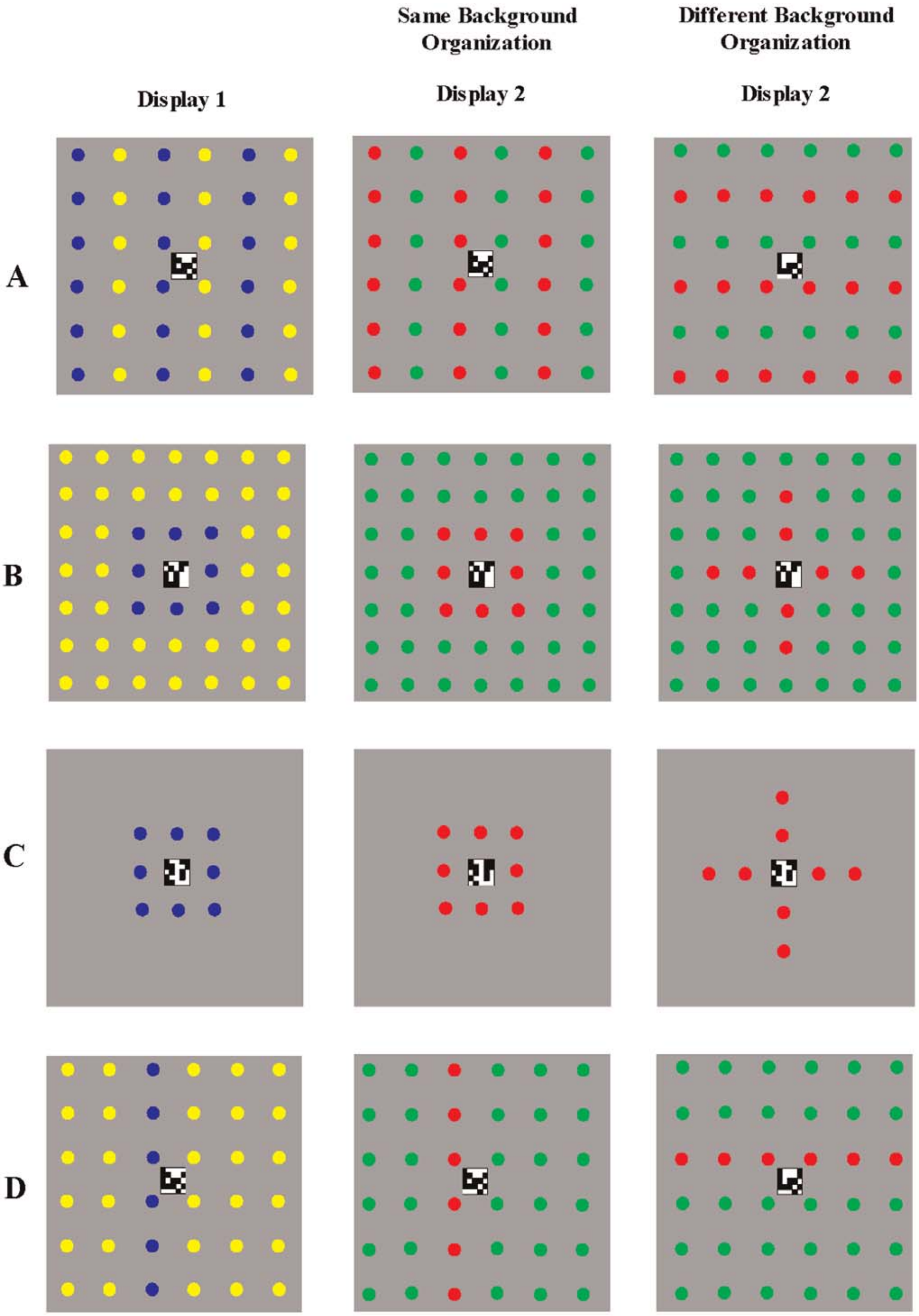

Fig. 3. Examples of the stimulus displays used by Kimchi and Razpurker Apfeld (2004). Two successive displays were presented on each trial. The central target matrix in Displays 1 and 2 were either the same or different. The surrounding colored elements were grouped into (A) columns/rows by color similarity, (B) a square/cross by color similarity, (C) a square/cross, (D) a vertical/horizontal line by color similarity. This background organization either stayed the same across Displays 1 and 2 or changed, independently of whether the target matrix changed or remained the same. The colors of the background elements always changed between Displays 1 and 2. All colors were equiluminant in the experiment. Adapted with permission from Kimchi and Razpurker Apfeld (2004). (See Color Plate 2.3 in color plate section.)

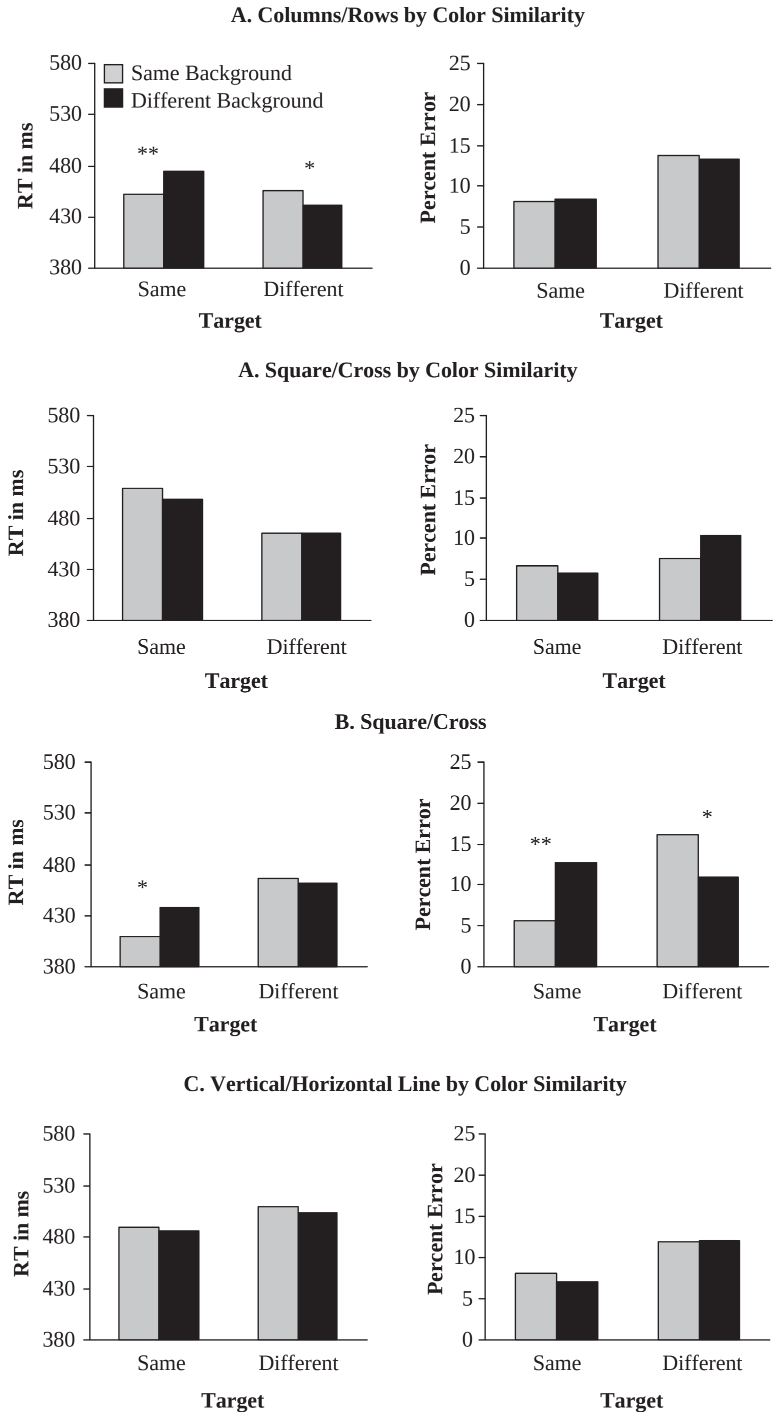

Fig. 4. Results from Kimchi and Razpurker Apfeld (2004). Mean correct reaction times (RTs) (left panel) and error rates (right panel) for target-same and target-different judgments as a function of background similarity (same or different) for each background condition (*$p < 0.05$; **$p < 0.01$). Adapted with permission from Kimchi and Razpurker Apfeld (2004).

under inattention, whereas the latter did not. Complexity of shape formation per se — forming a shape (e.g., a square or a cross) versus forming lines (columns or rows) — cannot account for this difference because grouping of shape occurred under inattention when no elements segregation was involved. Rather, it is grouping that involves both segregation and shape formation that appeared to require attention. We hypothesized that in this case there was a need to resolve figure-ground relations between groups — designating one of the groups as "figure." In the columns/rows condition, on the other hand, there was no such need because all segmented groups contribute to the global orientation of the pattern (vertical or horizontal). To examine this conjecture, we employed the condition depicted in Fig. 3D — vertical/horizontal line by color similarity. Shape formation for this grouping is as simple (if not simpler) as for the columns/rows (requiring only determination of the orientation of the grouped elements), but unlike the columns/rows, it also requires resolving figure-ground relations, as in the square/cross by color similarity. No influence of the background was observed for the vertical/horizontal line condition (Fig. 4D), suggesting that resolving figure-ground relation may demand attention (see Peterson and Salvagio, this volume).

These results indicate that both clustering and shape formation can take place without attention and thus are incompatible with the view of a dichotomy between these processes in terms of attentional demands (Trick and Enns, 1997).

Rather, these results suggest that a continuum of attentional demands exists as a function of the processes involved in organization and the conditions prevailing for each process. Grouping of columns/row by color similarity can occur under inattention (see also Russell and Driver, 2005; Shomstein et al., 2009). Grouping of shape can also take place without attention when no elements segregation is involved, but grouping of shape that involves elements segregation cannot, presumably because it requires resolving figure-ground relations between groups. Note that according to this view, it is possible, for example, that grouping into columns/rows could have demanded attention were it based on certain shape similarity instead of color similarity (e.g., arrows vs. crosses; see Han and Humphreys, 1999), or if the patterns were not easily resolved, as apparently was the case in Ben Av et al. (1992).

Similarly, figure-ground segmentation can occur without attention under certain conditions but not under others. Thus, in Kimchi and Peterson's (2008) study, figure-ground segmentation was based solely on convexity, which is a powerful cue for figural assignment in multiregion displays (e.g., Hoffman and Singh, 1997; Kanizsa and Gerbino, 1976; Peterson and Salvagio, 2008). It is possible, however, that when other, perhaps less potent, figural cues are involved, segmentation requires the scrutiny of focal attention. Also, resolution of cross-edge competition, which is required for figure-ground assignment when multiple competing cues are involved, may demand focal attention (see Peterson and Salvagio, this volume). Evidence that spatial attention can act as a cue for figure-ground assignment (Peterson and Gibson, 1994; Vecera et al., 2004) also casts serious doubt on the assumption that figure-ground segmentation must necessarily be completed prior to the deployment of focal attention.

Summary

The findings reviewed in the first part of this chapter provide evidence that some perceptual organization, such as some forms of grouping (e.g., grouping of columns/rows by color similarity, or grouping of shape when no elements segregation is involved) and figure-ground segmentation (e.g., figure-ground segmentation by convexity) can occur under inattention. Moore et al. (2003) showed that surface completion can also take place under inattention. Other organizations, however, appear to require focused attention (e.g., grouping of shape that involves elements segregation). Taken together, these findings suggest that perceptual organization is a multiplicity of processes that vary in their attentional demands. Regardless of attentional demands, the products of organization are not available to awareness without attention.

Can perceptual organization affect the automatic deployment of attention?

The critical role of perceptual organization in designating potential objects raises an important issue concerning the relations between perceptual organization and attention: When some elements in the visual scene are organized by Gestalt factors into a coherent perceptual unit (an object),[1] is visual attention automatically deployed to the object? Presumably, favoring a coherent perceptual unit that conforms to Gestalt factors is a desirable characteristic for a system whose one of its important goals is object identification and recognition, because these units are likely to imply objects in the environment.

In this part of the chapter I describe a series of experiments that my colleagues and I have conducted, as a part of an ongoing research, to examine whether the mere organization of some elements into an object, with no abrupt onset or any other unique transient, can capture attention automatically in a stimulus-driven manner, much as exogenous cues capture spatial attention automatically.

As noted earlier, several studies have demonstrated that perceptual organization can constrain attentional selectivity, supporting object-based theories of visual attention. None of these studies, however, show unequivocally that the object per se was the factor that attracted attention, because there were always other factors that directed attention to a part or an attribute of the object, either exogenously or endogenously. Thus, some studies employed a brief flicker presented in one end of the relevant object to exogenously summon attention (e.g., Egly et al., 1994; Moore et al., 1998), and other studies used central cues, instructions, or task-related factors to encourage observers to direct their attention to one of the objects or to its attributes (e.g., Behrmann et al., 1998; Duncan, 1984; Kramer and Jacobson, 1991).

[1]The question of what constitutes a perceptual object is a difficult one and yet to be answered (e.g., Scholl, 2001). I use the term object to refer to ''elements in the visual scene organized by Gestalt factors into a coherent unit.''

Perceptual objects capture attention

To examine whether an object by itself captures attention, it is crucial that the object has no abrupt onset or any other unique transient, and that the object is irrelevant to the task at hand so there is no incentive for the observer to deliberately attend to the object. To this end, my colleagues and I (Kimchi et al., 2007) modified a paradigm developed by Logan (1995) by substituting the O elements in Logan's original display with L elements in various orientations, and manipulating the organization in the display as described below.

Participants viewed a display composed of nine red and green L elements rotated at different angles and forming the vertices of four adjacent quadrants making up a global diamond (Fig. 5, top panel). The participants' task was to report the color of one of the elements as indicated by an asterisk presented in the center of one of the quadrants and an instruction word — ''above,'' ''below,'' ''right,'' or ''left'' — that preceded the elements display and specified the position of the target relative to the asterisk. For example, if the word was ''above,'' observers had to identify the color of the element above the asterisk. Each trial began with one of the instruction words, then the display appeared, and 150 ms after the display onset the asterisk appeared in the center of one of the quadrants (Fig. 5, bottom panel). Thus, performing the task required locating the asterisk, locating the target relative to the asterisk, and analyzing the target's color. On half of the trials, the four Ls of one of the quadrants were rotated so as to conform to the Gestalt factors of collinearity, closure, and symmetry, forming a diamond-like object. The asterisk appeared in the object quadrant (*Inside-object* condition, Fig. 5a) on 12.5% of all trials, and in a non-object quadrant (*Outside-object* condition, Fig. 5b) on 37.5% of all trials. On 50% of all trials no object was present in the display (*No-object* condition, Fig. 5c). The diamond-like object was task irrelevant (because the task-relevant feature was the color of a single element) and was not predictive of the relevant quadrant or the target. Moreover, no unique onset was associated with the object because it appeared simultaneously with the onset of the entire

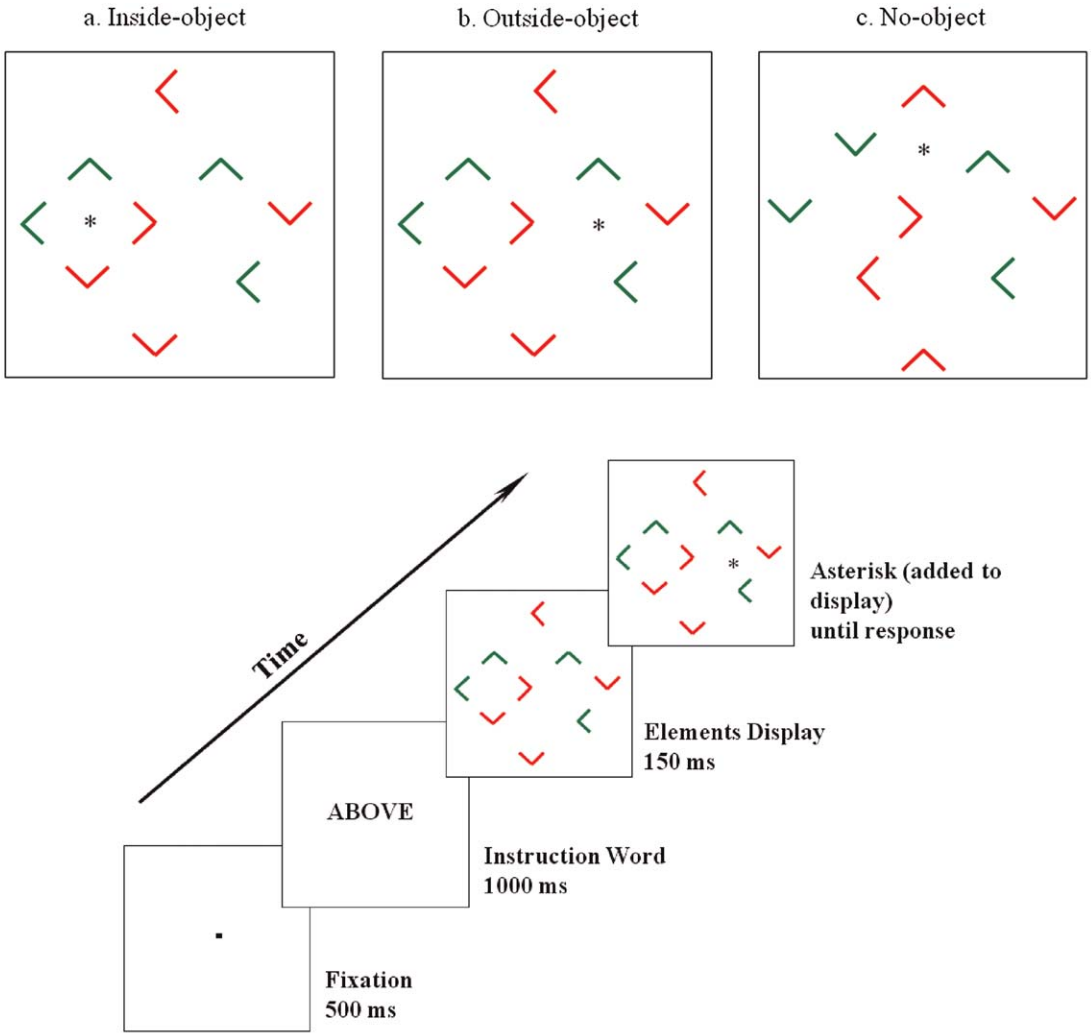

Fig. 5. Top panel: Examples of the displays used by Kimchi et al. (2007). Each display composed of nine red and green elements. (a) Inside-object condition: object present in display and asterisk appearing in center of object quadrant; (b) Outside-object condition: object present in display and asterisk appearing in center of nonobject quadrant; and (c) No-object condition: no object present in display. Fifty percent of the trials were No-object trials, 12.5% were Inside-object trials, and 37.5% were Outside-object trials. Bottom panel: Sequence of events in a trial. The illustration depicts an Outside-object trial with the instruction word *above*. In this trial, the participants had to identify the color of the element above the asterisk (green). Adapted with permission from Kimchi et al. (2007). (See Color Plate 2.5 in color plate section.)

elements display. This is a critical difference from previous research in which attention was captured by the unique appearance of an object defined by discontinuities in luminance, motion, texture, or depth (e.g., Yantis and Hillstrom, 1994; Franconeri et al., 2005). Thus, there was no top-down incentive for the participants to deliberately attend the object, nor was there any previously known stimulus-driven cue, such as feature-singleton, abrupt onset, or any other unique transient, to automatically attract attention to the object quadrant.

We hypothesized that if attention is automatically drawn to the object, then performance will be faster and/or more accurate in the Inside-object condition than in the No-object condition (a benefit) because attention is allocated in advance

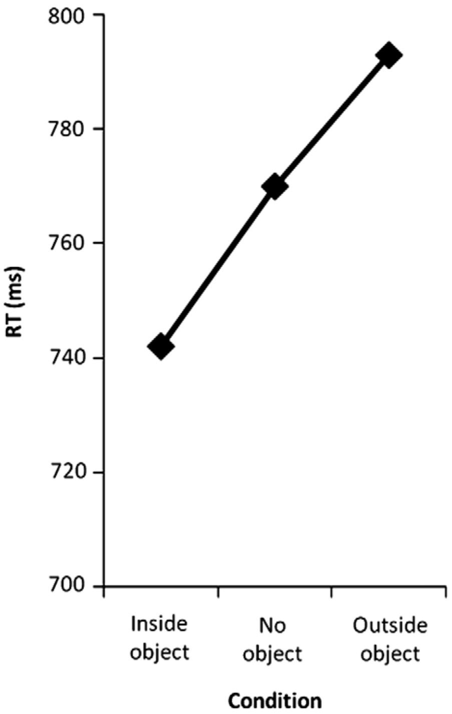

Fig. 6. Data from Kimchi et al. (2007). Mean correct reaction times (RTs) as a function of condition. Adapted with permission from Kimchi et al. (2007).

to the object quadrant, and slower and/or less accurate in the Outside-object condition than in the No-object condition (a cost), because attention has to be redirected from the object quadrant to the actual relevant quadrant. The results (see Fig. 6) showed the expected cost and benefit, demonstrating capture of attention by the irrelevant object.

Kimchi et al.'s (2007) study was the first to show unequivocal evidence for attentional capture by an object. There are, however, two concerns regarding this study. One is the extent to which the observed cost and benefit effects are somehow related to the complexity of the task. The task involved several operations and imposed memory load: Participants had to remember the instruction word, to locate the asterisk, to locate the target relative to the asterisk, and to analyze the target's color. Thus, the observed effects could be, at least partly, a function of task complexity and memory load.

A second concern is the extent to which the observed effects are a consequence of processes that are not necessarily related to attention. This concern arose because of the following observation. In the Outside-object condition, in which the asterisk appeared in a non-object quadrant, the target-element on some of the trials actually "belonged" to the object (i.e., it was one of the four elements forming an object in another quadrant), whereas on the other trials the target-element did not belong to the object. Analysis of the cost for these two types of trials showed costs for both with somewhat higher cost for target-elements that belonged to the object. This finding suggests that some of the observed cost could be attributed to difficulty in "extracting" an element that was already grouped into an object. Thus, the observed effects might be due to a mixture of attentional processes and other processes that are related to the actual processing of the object (e.g., extracting an element from an object).

The experiments described next, conducted in collaboration with Yaffa Yeshurun and Guy Sha'ashoua, addressed these issues by employing a simpler task and a target that is not part of the object.

To examine whether similar results indicating attentional capture by an object emerge with a simpler task that does not impose high memory load, we presented participants with a matrix of 16 black L elements in various orientations (Fig. 7, top panel). One of the Ls changed its color from black to red or orange 150 ms following the onset of the matrix. The task was to identify the color of the changed element. On half of the trials four elements were collinear, forming an object — a square. There were four possible locations where the object could appear (hence there were 12 possible target-elements). The object was present in the display on half of the trials. On 16.6% of all trials the target was an object's element (*Inside-object* condition, Fig. 7a). On 33.4% of all trials the target was a non-object element (*Outside-object* condition, Fig. 7b). On 50% of all trials the elements did not form an object, and the target was one of the twelve possible target-elements (*No-object* condition, Fig. 7c). Note that in the Outside-object condition, the target never belonged to the object. As in Kimchi et al.'s (2007) study, the object was task irrelevant and was not predictive of the target, nor was it associated with any unique transient. The results (Fig. 7,

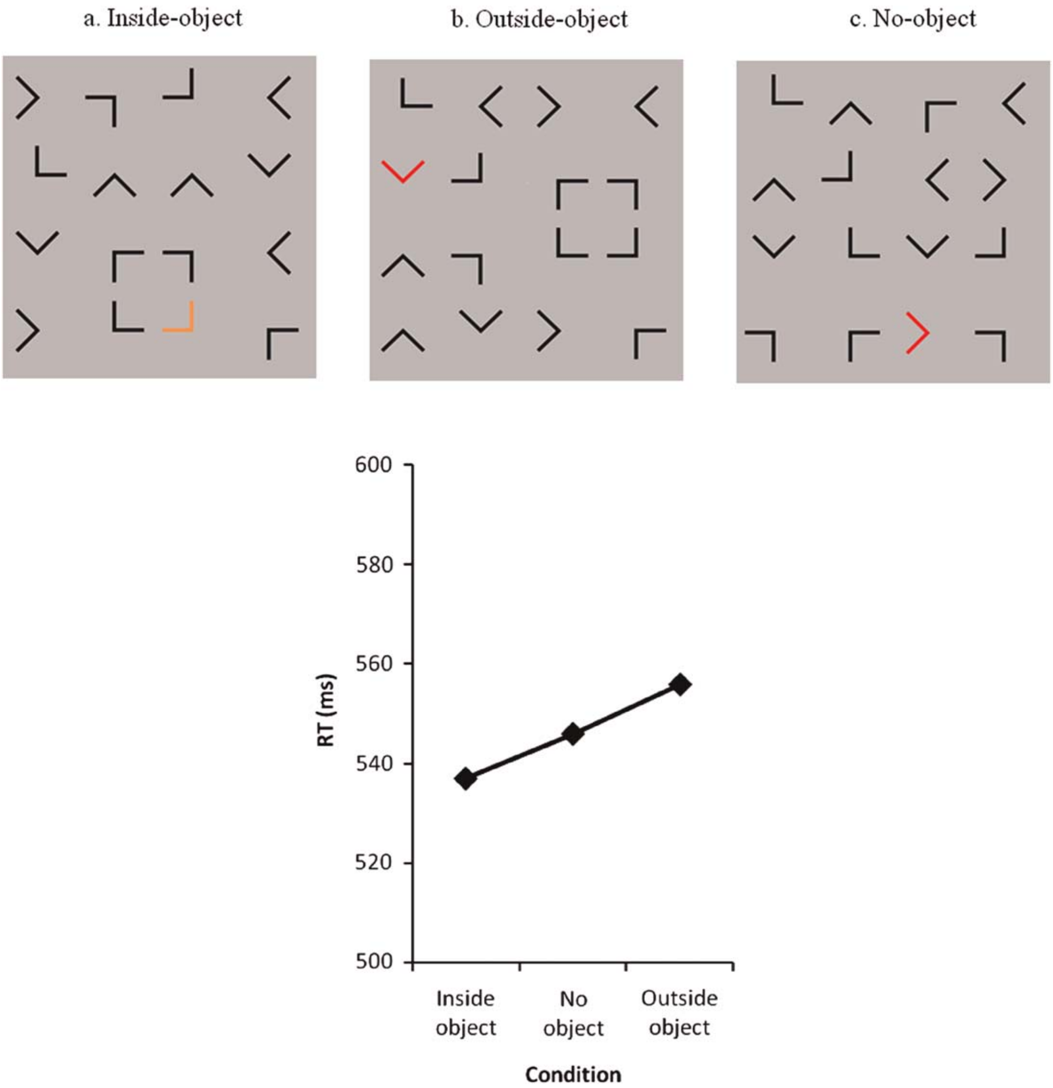

Fig. 7. Top panel: Examples of the displays in the three conditions. (a) Inside-object condition: object present in display and the target is an object element (16.6% of all trials); (b) Outside-object condition: object present in display and the target is a non-object element (33.4% of all trials); and (c) No-object condition: no object present in display (50% of all trials). Bottom panel: Mean correct reaction times (RTs) as a function of condition. (See Color Plate 2.7 in color plate section.)

bottom panel) showed the expected benefit and cost: performance on trials with an object in the display was faster than performance on trials with no object for object-element targets but slower for non-object-element targets, indicating that the object captured attention.

In a second experiment we examined whether a similar automatic attraction of attention by the object can be found with displays in which the target is never a part of the object and has no figural resemblance to the object. The target was a Vernier stimulus composed of two vertical lines with one line appearing above the other and separated by a small horizontal offset. The participants had to discriminate the direction of the offset (right or left). Participants were presented with a matrix of 36 black L elements in various orientations (Fig. 8, top panel). As in the

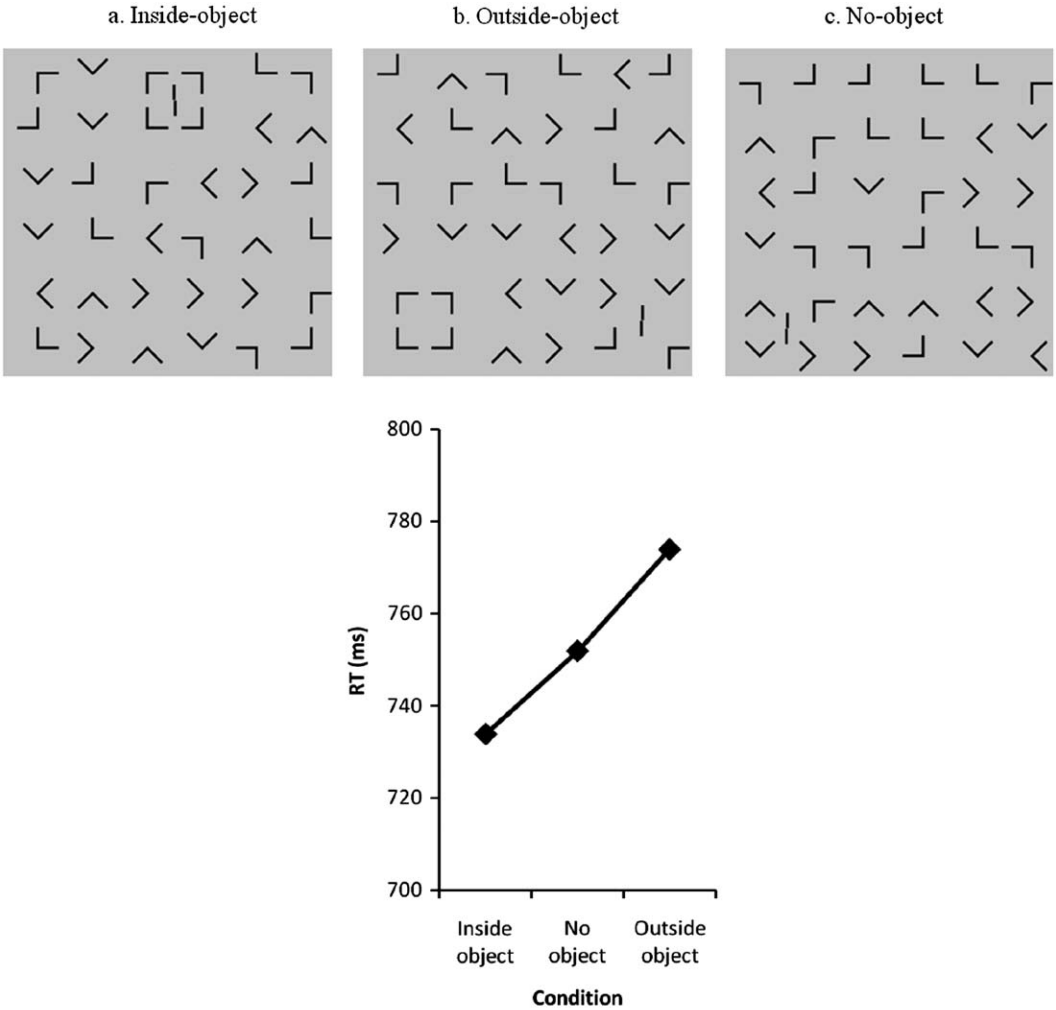

Fig. 8. Top panel: Examples of the displays in the three conditions. (a) Inside-object condition: object present in display and the Vernier target appears at the center of the object (9%of all trials); (b) Outside-object condition: object present in display and the target in another location (64% of all trials); and (c) No-object condition: no object present in display (27% of all trials). Bottom panel: Mean correct reaction times (RTs) as a function of condition.

previous experiment, an object — a square — was formed by four collinear elements. There were eight possible locations in which the object could appear. The Vernier target appeared 150 ms after the onset of the matrix. The Vernier target appeared at the center of the object on 9% of all trials (*Inside-object* condition, Fig. 8a), and outside the object — at one of the other seven possible locations — on 64% of all trials (*Outside-object* condition, Fig. 8b). On 27% of all trials the elements did not form an object, and the target appeared in one of the eight possible locations (*No-object* condition, Fig. 8c).[2] Thus, the matrix

[2]Given the larger number of target and object locations in this experiment, the ratio of Inside-object trials to Outside-object trails is highly in favor of the Outside-object condition. In order to allow for a reasonable number of Inside-object trials while keeping a reasonable number of total trials, we reduced the number of No-object trials. Consequently, the object appeared more frequently, but it was not predictive of target's location.

was completely irrelevant to the task and the object was not predictive of the target location or the direction of offset. Moreover, the Vernier target was never a part of the object. The results (Fig. 8, bottom panel) show that performance was faster when the target appeared in the center of the object (Inside-object condition) than in the No-object condition (benefit), and slower in the Outside-object condition than in the No-object condition (cost), demonstrating automatic attraction of attention to the object.

Summary

The results of the latter two experiments clearly demonstrate that the object-related cost and benefit effects observed in Kimchi et al.'s (2007) study do not depend on high memory load or on the target being a part of the object. These results provide corroborating evidence in support of the hypothesis that attention is automatically attracted to the object.

An automatic, stimulus-driven capture of attention by an object may provide a single account for a variety of "object advantage" effects reported in the literature, demonstrating the special status of objects for our visual system. These include more accurate discrimination of line segments when flashed on the figure than on the ground (Wong and Weisstein, 1982), easier detection of four target lines embedded in distractors when the lines are organized into a face-like pattern than a meaningless cluster (Gorea and Julesz, 1990), higher sensitivity for a target probe when positioned inside a circular contour embedded in a random background rather than outside the circle (Kovacs and Julesz, 1993), better memory for a figure's contour than for ground's contour (Driver and Baylis, 1996), and greater brain activation when the target appears in a region bounded by an object than in an unbounded region (Arrington et al., 2000).

Several outstanding questions await further research. These include uncovering the mechanisms underlying our object effect, examining whether the automatic deployment of attention is exclusively space-based or some combination of object-based and space-based components, and exploring which organization factors (e.g., collinearity, closure, symmetry, etc.) are necessary for an object to capture attention. We are pursuing these questions in ongoing research.

Concluding remarks

In this chapter I focused on two issues concerning the relationship between perceptual organization and visual attention. The first issue concerns the question of whether or not perceptual organization can be accomplished without attention. I reviewed findings demonstrating that some perceptual organization, such as some forms of grouping and figure-ground segmentation can occur without attention, whereas other forms of organization require controlled attentional processing, depending on the processes involved in the organization and the conditions prevailing for each process. These findings challenge the traditional view, which suggests that perceptual organization is a unitary entity that operates preattentively. Nor do they agree with the radical view of Mack and Rock (1998) that no Gestalt grouping can occur without attention. Rather, these findings support the view that perceptual organization is a confluence of multiple processes that vary in attentional demands (Behrmann and Kimchi, 2003; Kimchi, 2003; Kimchi and Razpurker Apfeld, 2004).

The second issue concerns the question of whether perceptual organization can affect the automatic deployment of attention. I presented findings showing that the mere organization of some elements in the visual field by Gestalt factors into a coherent perceptual unit (an object), with no abrupt onset or any other unique transient, can capture attention automatically in a stimulus-driven manner. It is well documented by now that objects play an important role in visual attention (e.g., Scholl, 2001). These findings, however, are the first to demonstrate that an object per se can attract attention automatically.

Taken together, the findings discussed in this chapter (and other findings reported in the literature) demonstrate that the relationship between perceptual organization and visual attention is multifaceted. Thus, a visual scene can be perceptually organized to a degree without attention, yet focused attention may be required to resolve competing organizations; attentional selection can be driven by organization in the visual scene, yet goal-driven attention can affect the organization of a visual scene. These intricate relations between perceptual organization and visual attention suggest a strong interaction between these two important functions of our perceptual system.

Acknowledgments

This chapter was supported in part by the Israel Science Foundation Grant No. 94/06 to the author and in part by Max Wertheimer Minerva Center for Cognitive Processes and Human Performance, University of Haifa.

References

Abrams, R. A., & Christ, S. E. (2003). Motion onset captures attention. *Psychological Science*, *14*(5), 427–432.

Arrington, C. M., Carr, T. H., Mayer, A. R., & Rao, S. M. (2000). Neural mechanisms of visual attention: Object-based selection of a region in space. *Journal of Cognitive Neuroscience*, *12*(Suppl. 2), 106–117.

Baylis, G. C., & Driver, J. (1992). Visual parsing and response competition: The effect of grouping factors. *Perception & Psychophysics*, *51*(2), 145–162.

Beck, J. (1982). Textural segmentation. In J. Beck (Ed.), *Organization and representation in perception* (pp. 285–317). Hillsdale, NJ: Lawrence Erlbaum Associates.

Behrmann, M., & Kimchi, R. (2003). What does visual agnosia tell us about perceptual organization and its relationship to object perception? *Journal of Experimental Psychology: Human Perception and Performance*, *29*(1), 19–42.

Behrmann, M., Zemel, R. S., & Mozer, M. C. (1998). Object-based attention and occlusion: Evidence from normal subjects and a computational model. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(4), 1011–1036.

Ben Av, M. B., & Sagi, D. (1995). Perceptual grouping by similarity and proximity: Experimental results can be predicted by intensity autocorrelations. *Vision Research*, *35*(6), 853–866.

Ben Av, M. B., Sagi, D., & Braun, J. (1992). Visual attention and perceptual grouping. *Perception & Psychophysics*, *52*(3), 277–294.

Braun, J., & Sagi, D. (1990). Vision outside the focus of attention. *Perception & Psychophysics*, *48*(1), 45–58.

Braun, J., & Sagi, D. (1991). Texture-based tasks are little affected by 2Nd tasks requiring peripheral or central attentive fixation. *Perception*, *20*(4), 483–500.

Chan, W. Y., & Chua, F. K. (2003). Grouping with and without attention. *Psychonomic Bulletin and Review*, *10*(4), 932–938.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*, 193–197.

Driver, J., & Baylis, G. (1996). Edge-assignment and figure-ground segmentation in short-term visual matching. *Cognitive Psychology*, *31*, 248–306.

Driver, J., & Baylis, G. C. (1989). Movement and visual attention: The spotlight metaphor breaks down. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 448–456.

Driver, J., Baylis, G. C., & Rafal, R. D. (1992). Preserved figure-ground segregation and symmetry perception in visual neglect. *Nature*, *360*, 73–75.

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

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

Egly, R., Driver, J., & Rafal, R. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General*, *123*, 161–177.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(4), 1030–1044.

Franconeri, S. L., Hollingworth, A., & Simons, D. J. (2005). Do new objects capture attention? *Psychological Science*, *16*(4), 275–281.

Freeman, E., Sagi, D., & Driver, J. (2001). Lateral interactions between targets and flankers in low-level vision depend on attention to the flankers. *Nature Neuroscience*, *4*(10), 1032–1036.

Freeman, E., Sagi, D., & Driver, J. (2004). Configuration-specific attentional modulation of flanker-target lateral interactions? *Perception*, *33*, 181–194.

Gorea, A., & Julesz, B. (1990). Context superiority in a detection task with line-element stimuli: A low-level effect. *Perception*, *19*(1), 5–16.

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye. In J. Long & A. Baddeley (Eds.), *Attention and performance IX* (pp. 187–203). Hillsdale, NJ: Erlbaum.

Julesz, B. (1981). Textons, the elements of texture-perception, and their interactions. *Nature*, *290*(5802), 91–97.

Hadad, B. S., & Kimchi, R. (2006). Developmental trends in utilizing perceptual closure for grouping of shape: Effects of spatial proximity and collinearity. *Perception & Psychophysics*, *68*(8), 1264–1273.

Han, S., & Humphreys, G. W. (1999). Interactions between perceptual organization based on Gestalt laws and those based on hierarchical processing. *Perception & Psychophysics*, *61*(7), 1287–1298.

Han, S., Humphreys, G. W., & Chen, L. (1999). Parallel and competitive processes in hierarchical analysis: Perceptual grouping and encoding of closure. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(5), 1411–1432.

Han, S. H. (2004). Interactions between proximity and similarity grouping: An event-related brain potential study in humans. *Neuroscience Letters*, *367*(1), 40–43.

Hoffman, D. D., & Singh, M. (1997). Salience of visual parts. *Cognition*, *63*(1), 29–78.

Hulleman, J., & Humphreys, G. W. (2004). A new cue to figure-ground coding: Top-bottom polarity. *Vision Research*, *44*(24), 2779–2791.

Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 181–211). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kanizsa, G., & Gerbino, W. (1976). Convexity and symmetry in figure-ground organization. In M. Henle (Ed.), *Vision and artifact* (pp. 25–32). New York: Springer.

Kimchi, R. (1998). Uniform connectedness and grouping in the perceptual organization of hierarchical patterns. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(4), 1105–1118.

Kimchi, R. (2000). The perceptual organization of visual objects: A microgenetic analysis. *Vision Research*, *40*(10–12), 1333–1347.

Kimchi, R. (2003). Visual perceptual organization: A microgenetic analysis. In R. Kimchi, M. Behrmann, & C. R. Olson (Eds.), *Perceptual organization in vision: Behavioral and neural perspectives* (pp. 117–154). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Kimchi, R., Hadad, B., Behrmann, M., & Palmer, S. E. (2005). Microgenesis and ontogenesis of perceptual organization: Evidence from global and local processing of hierarchical patterns. *Psychological Science*, *16*(4), 282–290.

Kimchi, R., & Peterson, M. A. (2008). Figure-ground segmentation can occur without attention. *Psychological Science*, *19*(7), 660–668.

Kimchi, R., & Razpurker Apfeld, I. (2004). Perceptual grouping and attention: Not all groupings are equal. *Psychonomic Bulletin and Review*, *11*(4), 687–696.

Kimchi, R., Yeshurun, Y., & Cohen Savransky, A. (2007). Automatic, stimulus-driven attentional capture by objecthood. *Psychonomic Bulletin and Review*, *14*(1), 166–172.

Klymenko, V., & Weisstein, N. (1986). Spatial frequency differences can determine figure-ground organization. *Journal of Experimental Psychology: Human Perception and Performance*, *12*, 324–330.

Koffka, K. (1935). *Principles of Gestalt psychology*. New York: Harcourt Brace Jovanovich.

Kovacs, I., & Julesz, B. (1993). A closed curve is much more than an incomplete one: Effect of closure in figure-ground segmentation. *Proceedings of the National Academy of Sciences of the United States of America*, *92*, 7495–7497.

Kovacs, I., Kozma, P., Feher, A., & Benedek, G. (1999). Late maturation of visual spatial integration in humans. *Proceedings of the National Academy of Sciences of the United States of America*, *96*(21), 11209–12204.

Kramer, A. F., & Jacobson, A. (1991). Perceptual organization and focused attention: The role of objects and proximity in visual processing. *Perception & Psychophysics*, *50*, 267–284.

Kurylo, D. D. (1997). Time course of perceptual grouping. *Perception & Psychophysics*, *59*(1), 142–147.

Lamy, D., Segal, H., & Ruderman, L. (2006). Grouping does not require attention. *Perception & Psychophysics*, *68*(1), 17–31.

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

Logan, G. D. (1995). Linguistic and conceptual control of visual spatial attention. *Cognitive Psychology*, *28*(2), 103–174.

Mack, A., & Rock, I. (1998). *Inattentional blindness*. Cambridge, MA: MIT Press/Bradford Books series in cognitive psychology, The MIT Press.

Mack, A., Tang, B., Tuma, R., Kahn, S., & Rock, I. (1992). Perceptual organization and attention. *Cognitive Psychology*, *24*, 475–501.

Marr, D. (1982). *Vision*. San Francisco, CA: W. H. Freeman.

Martinez, A., Teder-Salejarvi, W., & Hillyard, S. A. (2007). Spatial attention facilitates selection of illusory objects: Evidence from event-related brain potentials. *Brain Research*, *1139*, 143–152.

Martinez, A., Teder-Salejarvi, W., Vazquez, M., Molholm, S., Foxe, J. J., Javitt, D. C., et al. (2006). Objects are highlighted by spatial attention. *Journal of Cognitive Neuroscience*, *18*(2), 298–310.

Moore, C., & Egeth, H. (1997). Perception without attention: Evidence of grouping under conditions of inattention. *Journal of Experimental Psychology: Human Perception and Performance*, *23*(2), 339–352.

Moore, C., Yantis, S., & Vaughan, B. (1998). Object-based visual selection: Evidence from perceptual completion. *Psychological Science*, *9*(2), 104–110.

Moore, C. M., Grosjean, M., & Lleras, A. E. (2003). Using inattentional blindness as an operational definition of unattended: The case of surface completion. *Visual Cognition*, *10*(3), 299–318.

Neisser, U. (1967). *Cognitive psychology*. New York: Appleton Century Crofts.

Nelson, R. A., & Palmer, S. E. (2007). Familiar shapes attract attention in figure-ground displays. *Perception & Psychophysics*, *69*, 382–392.

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

Palmer, S. E. (1992). Common region: A new principle of perceptual grouping. *Cognitive Psychology*, *24*, 436–447.

Palmer, S. E., & Ghose, T. (2008). Extremal edges: A powerful cue to depth perception and figure-ground organization. *Psychological Science*, *19*(1), 77–84.

Peterson, M. A., & Gibson, B. S. (1994). Object recognition contributions to figure-ground organization: Operations on outlines and subjective contours. *Perception & Psychophysics*, *56*(5), 551–564.

Peterson, M. A., & Salvagio, E. (2008). Inhibitory competition in figure-ground perception: Context and convexity. *Journal of Vision*, *8*(16), 1–13.

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

Quinn, P. C., & Bhatt, R. S. (2005). Good continuation affects discrimination of visual pattern information in young infants. *Perception & Psychophysics*, *67*(7), 1171–1176.

Quinn, P. C., & Bhatt, R. S. (2006). Are some Gestalt principles deployed more readily than others during early development? The case of lightness versus form similarity. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(5), 1221–1230.

Quinn, P. C., Bhatt, R. S., Brush, D., Grimes, A., & Sharpnack, H. (2002). Development of form similarity as a Gestalt grouping principle in infancy. *Psychological Science*, *13*(4), 320–328.

Quinn, P. C., Burke, S., & Rush, A. (1993). Part-whole perception in early infancy: Evidence for perceptual grouping produced by lightness similarity. *Infant Behavior and Development*, *16*(1), 19–42.

Razpurker Apfeld, I., & Kimchi, R. (2007). The time course of perceptual grouping: The role of segregation and shape formation. *Perception & Psychophysics*, *69*(5), 732–743.

Rock, I. (1986). The description and analysis of object and event perception. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance* Vol. 33, (pp. 1–71). New York: Wiley.

Rock, I., Linnet, C. M., Grant, P., & Mack, A. (1992). Perception without attention: Results of a new method. *Cognitive Psychology*, *5*, 504–534.

Rubin, E. (1921). *Visuell Wahrgenommene Figuren*. Kobenhaven: Glydenalske boghandel.

Russell, C., & Driver, J. (2005). New indirect measures of ‘‘inattentive’’ visual grouping in a change-detection task. *Perception & Psychophysics*, *67*(4), 606–623.

Scholl, B. J. (2001). Objects and attention: The state of the art. *Cognition*, *80*(1–2), 1–46.

Shomstein, S., Kimchi, R., Hammer, M., & Behrmann, M. (2009). *Perceptual grouping operates independently of attentional selection: Evidence from hemispatial neglect*. Manuscript submitted for publication.

Theeuwes, J., De Vries, G. J., & Godjin, R. (2003). Attentional and oculomotor capture with static singletons. *Perception & Psychophysics*, *65*(5), 735–746.

Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology: Human Perception and Performance*, *8*, 194–214.

Treisman, A. (1985). Preattentive processing in vision. *Computer Vision, Graphics, and Image Processing*, *31*, 156–177.

Treisman, A. (1988). Features and objects: The fourteenth Bartlett memorial lecture. *Quarterly Journal of Experimental Psychology*, *40A*(2), 201–237.

Trick, L. M., & Enns, J. M. (1997). Clusters precede shapes in perceptual organization. *Psychological Science*, *8*, 124–129.

Vecera, S., & Farah, M. J. (1994). Does visual attention select objects or locations? *Journal of Experimental Psychology: Human Perception and Performance*, *123*(2), 1–14.

Vecera, S. P., Flevaris, A. V., & Filapek, J. C. (2004). Exogenous spatial attention influences figure-ground assignment. *Psychological Science*, *15*(1), 20–26.

Vecera, S. P., Vogel, E. K., & Woodman, G. F. (2002). Lower region: A new cue for figure-ground assignment. *Journal of Experimental Psychology: General*, *131*(2), 194–205.

Wertheimer, M. (1923/1955). Gestalt theory. In: W.D. Ellis (Ed.), *A source book of Gestalt psychology* (pp. 1–16). London: Routhedge and Kegan Paul. (Originally published in German, 1923, London.)

Wong, E., & Weisstein, N. (1982). A new perceptual context-superiority effect: Line segments are more visible against a figure than against a ground. *Science*, *218*, 587–589.

Yantis, S., & Hillstrom, A. P. (1994). Stimulus-driven attentional capture: Evidence from equiluminant visual objects. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(1), 95–107.