Figural Completion in Visual Search

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CHAPTER I

Synopsis

General Introduction

Despite the vast quantity of information that is continuously extracted from the ambient visual array our perception seems both accurate and effortless. To achieve a consistent representation of the visual world, a series of complex operations is performed in order to integrate information into meaningful and coherent units (i.e. Marr, 1982). However, in most cases, the relation between external information and corresponding internal representation is ambiguous. This becomes evident when considering how information is transmitted to the brain. Natural scenes consist of three-dimensional objects while retinal projections resolve the image only in two dimensions. Consequently, to decide between possible interpretations of ambiguous viewing patterns, mechanisms are necessary to ensure correct interpretation of incoming visual information. One major challenge for a consistent interpretation of the environment is the question of how occluded object-parts without local stimulus correlates are to be integrated. Figure 1 depicts an example of a natural scene containing multiple objects that overlap, thus, providing ambiguous part-whole relations. Nevertheless, the assignment of cluttered parts to an integrated representation is achieved correctly without effort.

Figure 1 Object integration in natural scenes. The picture shows several partly occluded bears that are integrated into coherent representations on the basis of (modal and amodal) object completions.

The completion of occluded object parts has been termed ‘amodal’ completion (Michotte, Thines & Crabbe, 1964) to refer to the absence of sensory aspects that are missing behind occluders. Hereby, missing distal information is actively completed (i.e. Ramachandran & Gregory, 1991). However, object completion despite occlusion may represent an important but not the only case where the visual system deals with parts of an object that do not poses a physical correspondence. Besides amodal completion, ‘modal’ completion has been introduced as a second major source of integrative processes in object perception. Whereas amodal representations refer to object completions behind occluders, modal completion occurs when parts of an object are camouflaged because the neighboring surface happens to project the same luminance and color. From an evolutionary perspective, modal completion has been described as an anti-camouflage device that detects non-accidental properties of otherwise hidden objects in natural environments (Ramachandran, 1987). In support for this claim, mammals, birds and insects are able to perceive modal object completions (Nieder, 2002; for review).

Illusory Figures

In experimental settings, modal completion has been studied by the phenomenon of illusory figure perception (i.e. Petry & Meyer, 1987; Purghe & Coren, 1992; Spillmann & Dresp, 1995; Lesher, 1995). Illusory figures provide a phenomenal illusion of a surface or a line in the absence of luminance gradients. The first illusory figure was introduced by Schumann and consisted of semicircles that opposed each other across a gap (Schumann, 1900; see Figure 2a). Considering the reproduction of his Figure, in the empty region between semicircles, Schumann observed a central “white rectangle with sharply defined contours … which objectively are not there”, specifying the first illusory figure with sharp contours and a surface brighter than the background. Subsequently, Ehrenstein (1941) described a comparable figure showing an illusory brightness enhancement. As shown in the example of the Ehrenstein illusion in Figure 2b, a disc with enhanced brightness appears between converging lines. Finally, Kanizsa (1955; 1979) introduced another very popular stimulus configuration producing a brightness enhancement that is surrounded by sharp boundaries comparable to Schumann’s figure. Figure 2c illustrates such a Kanizsa triangle that can be described phenomenally as a

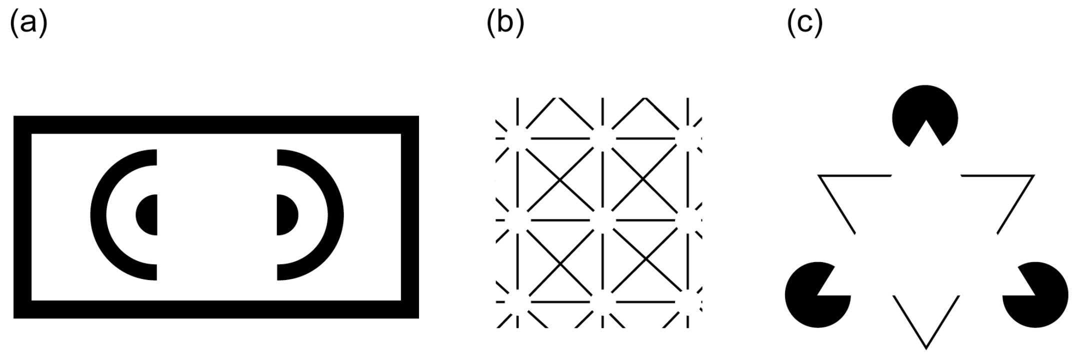

Figure 2 Classical examples of illusory figures. Panel (a) depicts Schumann's first example of an illusory figure (1900). Panel (b) illustrates the Ehrenstein brightness illusion (1941). Finally, panel (c) gives an example of the Kanizsa triangle (1955).

"white triangle having margins without gradients on three black disks and on a white triangle with a black border" (Kanizsa, 1979). In the example, the appearance of the illusory triangle illustrates integration beyond 'local' Gestalt grouping operations based on proximity, good continuation and closure (see Wertheimer, 1923; Koffka, 1935). Rather, a 'global' figure emerges that is qualitatively different from background, illustrating three perceptual effects that are usually associated with the phenomenon: a central figure having clear edges, a depth difference between the illusory surface and the adjacent objects and a brightness enhancement for the central illusory figure.

These classical examples provide first reports of illusory figure formation. To systematically classify the variety of phenomena, several types may be distinguished. According to Lesher (1995), illusory figures can either be induced from edges (such as in a Kanizsa figure) or from line ends (as in the Ehrenstein figure). In addition, illusory contours can arise with or without a corresponding surface. Figure 3 provides examples of both illusory figures that induce an emergent surface (panels a and b) and illusory

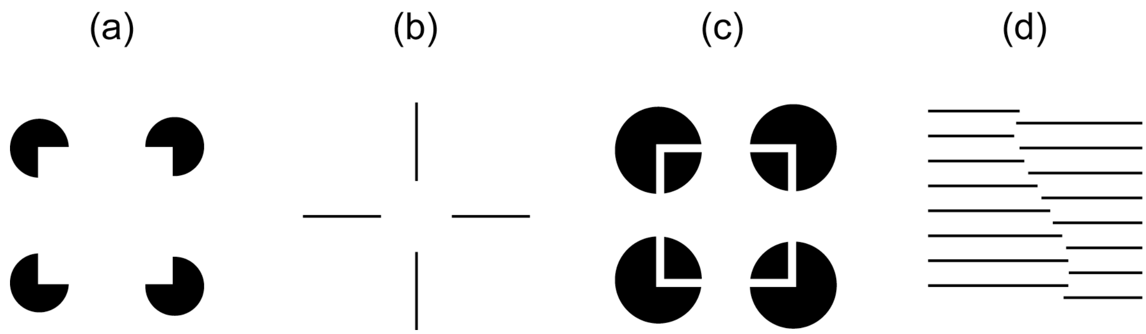

Figure 3 Examples of edge-induced (panel a, c) and line-end induced (panel b, d) illusory figures that either support the emergence of an illusory surface (panel a, b) or a contour without corresponding surface characteristics (panel c, d).

contours without corresponding emergent surfaces (panels c and d). In the examples, both types of illusory figures can either be induced from edges (panels a and c) or from lines (panels b and d). Consequently, on the one hand, illusory contours involve the percept of a clear boundary where there is no corresponding luminance gradient. On the other hand, an illusory figure may comprise surface characteristics that result in figural brightness enhancements and depth stratification. However, both contour interpolation and brightness filling-in seem to occur independent of each other while separate underlying processes code the illusory figure at multiple stages of integration (i.e. Dresp, Salvano-Pardieu & Bonnet, 1996).

Theories of illusory figure formation

To explain illusory figure formation, a variety of theories have been advanced. Initial explanations primarily focussed on isolated aspects of illusory figures. These approaches will be referred to as Gestalt-, brightness-, depth- and cognitive theories. Subsequently, computational models will be introduced. These were in the main, constructed to simulate neural mechanisms responsible for a variety of processes underlying the integration of illusory shape information.

Gestalt theories: Gestalt psychologists (i.e. Wertheimer, 1923; Koffka, 1935) have established an approach to illusory (and real) figures based upon the phenomenological description and identification of the perceived attributes contained in a stimulus configuration. Within this general framework, Kanizsa (1955) interpreted the emergence of illusory figures as a consequence of the ‘poor form’ of the inducers. Each inducer on its own was considered incomplete in the Gestalt sense, while the integration of separate elements into a global representation could offer a more regular, simple and stable percept. In addition, a related concept was offered by coding theory, demonstrating how a quantitative description of simplicity may benefit from the interpretation of a given configuration in terms of an illusory figure (van Tujil & Leeuwenberg, 1982).

Brightness theories: In addition to Gestalt approaches, brightness theories have intended to explain the underlying structure of the illusory luminance enhancement that accompanies the generation of an illusory form. Ehrenstein (1941) proposed a critical role for eye movements to explain brightness enhancements, however, this approach could not be supported by appropriate empirical investigations (see Lesher, 1995; Spillmann & Dresp, 1995; for review). Instead, recent approaches have shown that brightness filling-in may be observed in a variety of phenomena (see Pessoa, Thompson & Noë, 1998; Pessoa & De Weerd, 2003) including stereo capture (Ramachandran & Cavanagh, 1985) and neon colour spreading (Nakayama & Shimojo, 1992). To account for surface completion phenomena in general, Nakayama and Shimojo (1992) postulated ‘perceptual inference’ as a low-level mechanism that is implemented in the neural system to enable identification of illusory surfaces within a given scene.

Depth theories: Coren (1972) proposed a third major explanatory initiative to understand the emergence of illusory figures. His ‘depth cue’ theory posited that occlusion of inducer elements acts as a depth cue for illusory figure formation. According to this approach, the registration of depth cues (such as the inducers of a Kanizsa figure) has the effect that appropriate surfaces are added. Consequently, ‘interposition’ of related elements is thought to account for the completion of illusory figures.

Cognitive theories: An aspect of illusory figure formation referred to as ‘cognitive’ was forwarded by Gregory (1972) and Rock and Anson (1979). Within this framework, illusory figures are not regarded solely as the output of automatic sensory processes acting on the physical stimulus, but rather as a result of ‘hypothesis testing’ on the basis of what the perceiver implicitly knows about objects and their appearance in natural environments. For example, a Kanizsa square might be formed on the basis of this conception because a square occluding the inducer disks can be considered the most plausible hypothesis. While other approaches also stressed a certain ‘constructive’ nature of illusory figure formation, the postulation of cognitive, inferential processes suggests that high-level operations are exclusively responsible for the generation of illusory figures. A low-level variant of this approach might refer to the construction of surfaces from perceptual inference as described in the context of brightness theories (see Nakayama & Shimojo, 1992).

Computational models: Taken together, the theoretical considerations presented so far have generally focussed upon selective attributes of illusory figures (i.e. surfaces, depth) while presenting fairly abstract levels of explanation. To cope with this disadvantage, neural models intended to simulate underlying processes that attempted to explain a broader variety of phenomena. For example, Kellman and Shipley (1991) have suggested that both modal and amodal object integration could be derived from a single boundary completion processes that relates physically specified edges to corresponding interpolated contours. In addition, a series of computational models have proposed low-level simulations of physiological recordings (see next section) to account for both real and illusory contour formation in primary striate and extrastriate areas (Finkel & Edelman, 1989; Heitger, von der Heidt, Peterhans, Rosenthaler & Kübler, 1998). Finally, Grossberg and Mingolla (1985; 1987) have proposed an influential model that accounts for a variety of phenomena including perceptual grouping, boundary completion, illusory figure formation and neon color spreading. In their model, two independent modules establish boundaries of objects and respective color and brightness levels by means of two parts termed the boundary- and feature (i.e. surface) contour systems. According to this view, illusory figures might not be represented by a unitary mechanism. Rather, computational models postulate a series of processing steps necessary to provide appropriate representations of an illusory figure. As will be shown in the next section, physiological recordings support this conception of a multi-stage model.

Neural correlates of illusory figure representations

Given the complexity of an emergent figure arising from presentation of relatively simple aligned inducing elements, one unexpected result from single cell recordings was that cells early in the visual hierarchy are capable of signalling an illusory contour stimulus (von der Heydt, Peterhans & Baumgartner, 1984). Early visual cortical areas V1 and V2 showed responses to illusory contours within their receptive fields comparable to real contours defined by a luminance gradient (von der Heydt et al., 1984; Peterhans & von der Heydt, 1991; Sheth, Sharma, Chenchal Rao & Sur, 1996; Lee & Nguyen, 2001). While activations specific to illusory contours have also been found in striate and extrastriate visual areas in humans (Ffytche & Zeki, 1996; Murray, Wylie, Higgins, Javitt, Schroeder & Foxe, 2002; Ritzl, Marshall, Weiss, Zafiris, Shah, Zilles & Fink, 2003), a second major source of processing has also been located in the lateral occipital complex (LOC) and fusiform gyrus (Hirsch, de la Paz, Relkin, Victor, Kim, Borden, Rubin & Shapley, 1995; Stanley & Rubin, 2003; Halgren, Mendola, Chong & Dale, 2003). In agreement with extrastriate sources of illusory figure perception, human electrophysiological correlates typically have been reported in the N1 component peaking at ~80-150 ms after stimulus onset at occipito-parietal sources (Murray et al. 2002; Pegna, Khateb, Murray, Landis & Michel, 2002; Murray, Foxe, Javitt & Foxe, 2004). Consequently, activity elicited by illusory figures seems to be represented in various regions specialized in object processing with specific contributions from early and midlevel areas involved in visual processing.

Early V1 and V2 activations within this pattern could reflect the interpolation of contours. In addition, responses from the LOC and fusiform gyrus may be interpreted as a contribution to the filling-in of surface information. This filling-in of surfaces in LOC has also been attributed to some broader detection process of salient region computations in the visual field while exact contour interpolations may only result from a subsequent back-projection to earlier visual areas (Stanley & Rubin, 2003). Thus, the percept of an illusory figure may be accomplished by cascading forward and feedback projections between visual areas that support the identification of objects along the ventral stream (see also Sheth et al. 1996; Lee & Nguyen, 2001; Roelfsma, Lamme, Spekrejise & Bosch, 2002 for related evidence). Taken together, a variety of results provide evidence for a widely distributed network engaged in the processing of illusory shapes.

Visual search for illusory figures

Neuronal responses to illusory figures suggest the involvement of mechanisms that can be related to early (and midlevel) regions in the visual processing hierarchy. To relate outcomes from physiological studies to behavioral measures, psychophysical investigations attempted to uncover the underlying processes of object completions by employing visual search techniques. Experiments typically require observers to search for a target among distracter items while reaction time (RT) measurements or the processing time per item allow a distinction between efficient and inefficient search (Treisman & Gelade, 1980). Within this framework, efficient search performance is interpreted as the parallel allocation of attentional resources across the visual field, whereas inefficient search would indicate focused attention leading to a serial scanning of candidate target locations. In support of this differentiation, efficient target detection typically depends upon the presence or absence of a salient feature (color, orientation) that is encoded by specialized analyzers (i.e. color- or luminance sensitive cells) at early stages of visual processing (Treisman & Gormican, 1988; Wolfe & Horowitz, 2004). By contrast, inefficient performance is observed in experiments where separate features need to be combined into a unitary representation that is exploited for target detection (Treisman & Gelade, 1980).

Contrasting with this asymmetry between efficient ‘pop-out’ and inefficient ‘feature conjunction’ search, a series of results could demonstrate that analysis of complex units supports integration of fragments without effort. For example, perceptual configurations may be processed with higher efficiency than isolated components (Pomerantz, Sager & Stoever, 1977). In addition, visual search has shown that component parts may be grouped prior to the engagement of attention (Donnelly, Humphreys & Riddoch, 1991; Rensink & Enns, 1995; Moore & Egeth, 1997). Furthermore, visual search studies that investigated how occlusion affects target detection could demonstrate, that integrated object information is available at early stages of processing (He & Nakayama, 1992; Rensink & Enns, 1998). For example, search for a notched square could be performed efficiently. However, search for an identical target becomes inefficient when the arrangement of the target configuration is altered such that amodal completions of part structures are triggered (Rensink & Enns, 1998). Consequently, efficient search does not simply depend upon the presence or absence of an isolated feature dimension such as orientation or color. A series of experimental results suggest that at least in some cases, integrated object parts form a basis for efficient performance in search.

Besides studies investigating the role of element-groupings in visual search, modal completion has been employed as another example to investigate how an emergent figure is coded at early stages of processing. According to this approach, an illusory figure is defined as the target configuration and is to be detected as fast as possible

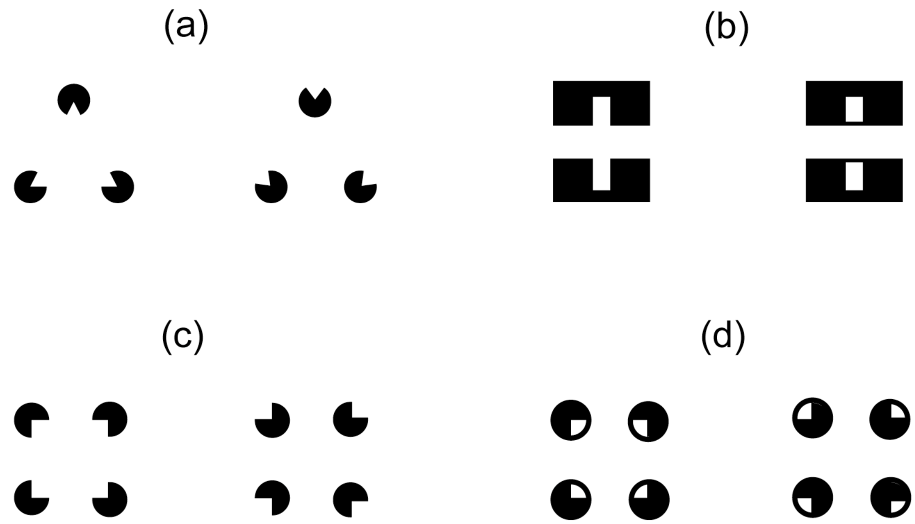

Figure 4 Example target and distracter configurations from visual search studies employing illusory figures. Each stimulus pair shows a target (left) and a corresponding distracter configuration (right). (a) Target Kanizsa triangle and distracter configuration employed by Grabowecky and Treisman (1989). (b) Illusory target figure and distracter configuration employed by Gurnsey et al. (1996) as a comparison to the stimuli employed in physiological recordings (see von der Heydt, et al., 1984). (c) Target Kanizsa square and distracter configuration employed by Davis & Driver (1994). (d) Target square and distracter configuration employed in a control experiment by Davis & Driver (1994).

amongst a set of distracter configurations that constitute the same inducer elements, however, this time rearranged so as not to form an illusory figure (see Figure 4 for example target and distracter configurations). Applying this paradigm, one study could show that illusory contours from offset gratings can be detected in parallel (Gurnsey, Humphrey & Kapitan, 1992). By contrast, a study by Grabowecky and Treisman (1989; see Figure 4a) reported that search for target Kanizsa figures was dependent from the number of distracter items that are present simultaneously in the visual field. However, by carefully reconsidering this setup, Davis and Driver (1994) reported that an illusory Kanizsa figure could be detected in parallel if conditions for detection were made optimal. In a series of experiments, they demonstrated that a Kanizsa square could be searched for independent from the number of non-targets presented simultaneously in the visual field (see Figure 4c). By contrast, a suppression of the emergent Kanizsa figure resulted in inefficient search (see Figure 4d). Consequently, this outcome was interpreted as providing a psychophysical correlate to the results from physiological studies (Peterhans & von der Heydt, 1991) and as an indication that the illusory figure is coded for efficient search.

However, this accordance between different approaches was seriously questioned in a follow-up study (Gurnsey, Poirier & Gascon, 1996). A series of experiments demonstrated an independence of search from the presence or absence of an illusory contour in candidate configurations. For example, search for Kanizsa-type square arrangements could be performed in parallel; by contrast, illusory contour stimuli as employed in physiological studies (von der Heydt et al., 1984; see Figure 4b) gave rise to serial self-terminating search. Finally, if observers were presented with square target and distracter arrangements composed from L-corner junctions (which do not induce illusory contours), target detection followed parallel search. Thus, search efficiency clearly depends on factors other than the presence or absence of an illusory contour. Consequently, the role of illusory figure processing in visual search remains undecided without making explicit how illusory figures are coded for search.

Overview of the current study

The experiments presented in the following four chapters of this cumulative dissertation were performed to investigate the role of form completions in search. To approach this issue, both reaction time (RT) and electroencephalographic (EEG) methods were employed. To begin, in Chapter II a series of visual search and rating experiments are introduced that investigate which object attributes are coded for Kanizsa figure target detection. Subsequently, in Chapter III, related evidence from an EEG experiment is presented that suggests an N2pc component as a physiological correlate of Kanizsa figure selection on the basis of emergent form information. Following this investigation of detection performance for illusory figures, in Chapter IV experiments are described that investigate search performance for stimuli that are grouped on the basis of closure and collinearity without forming an illusory figure. Finally, to complement this description of configural factors influencing (bottom-up) target detectability, Chapter V investigates how performance is modulated by (top-down) task requirements. Experiments are presented that compare detection performance with identification in search displays containing illusory figures and corresponding distracters.

Chapter II: Given equivocal results from previous studies that employed Kanizsa figures (Grabowecky & Treisman, 1989; Davis & Driver, 1994; Gurnsey et al., 1996), the current contribution investigated the relevance of coding several object attributes for successful detection of a target. Object attributes of a Kanizsa figure were considered at two distinct levels of organization, a local and a global level (see Rauschenberger & Yantis, 2001). On one hand, at the local level of the Kanizsa figure, inducing elements ('pacmen') correspond to the 'physical reality'. On the other hand, the global level comprises the emergence of an illusory square, exhibiting surface characteristics and respective borders that surround the figure (Grossberg & Mingolla, 1985; 1987; Lesher, 1995, Spillmann & Dresp, 1995). Consequently, at least three object attributes were

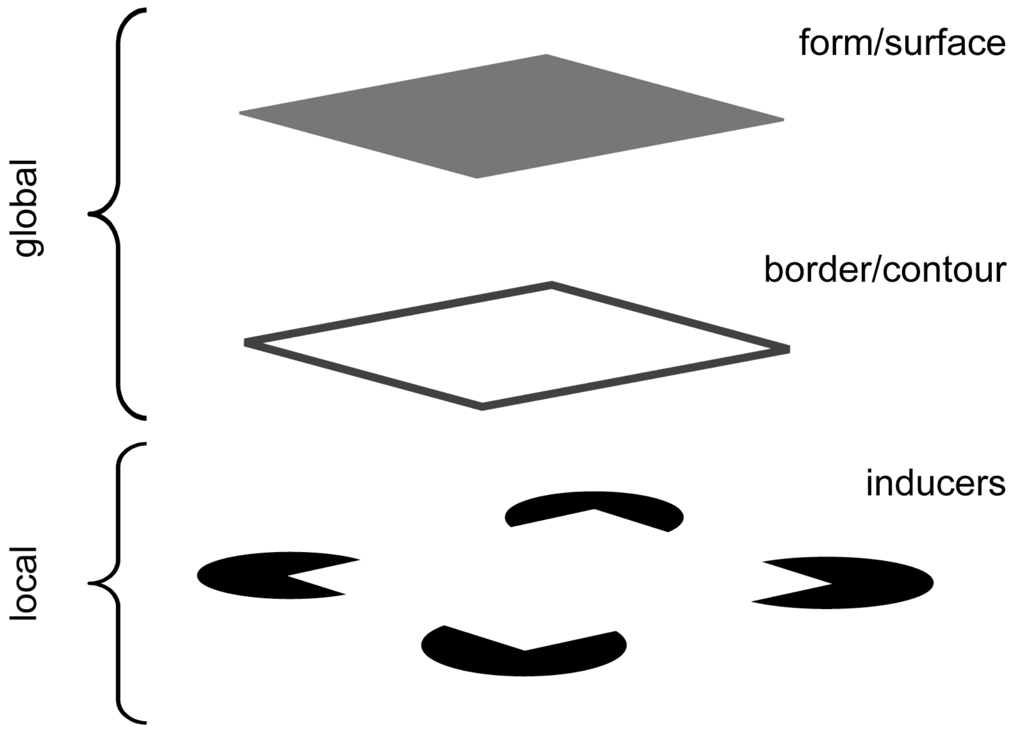

Figure 5 Illustration of local and global perceptual representations of an illusory Kanizsa figure. The local level consists of physically specified inducer elements. At the global level, an emergent square arises with contributions from mechanisms that interpolate illusory contours and mechanisms that fill-in surface information (see Grossberg & Mingolla, 1985).

distinguished: local inducers, global borders and global form (see Figure 5 for an illustration).

To decide which of these attributes are predominantly processed, a series of visual search (and related subjective rating) experiments were performed that systematically varied similarity aspects of targets and distracters. As has been shown (Duncan and Humphreys, 1989), the similarity relations between targets and distracter are a major determinant of search efficiency. Consequently, this relation was systematically explored in the current experiments with respects to each object attribute specified for global and local levels by introducing systematic variations in distracter compositions (see Figure 6 for an illustration of local configurations and corresponding global stimulus expressions).

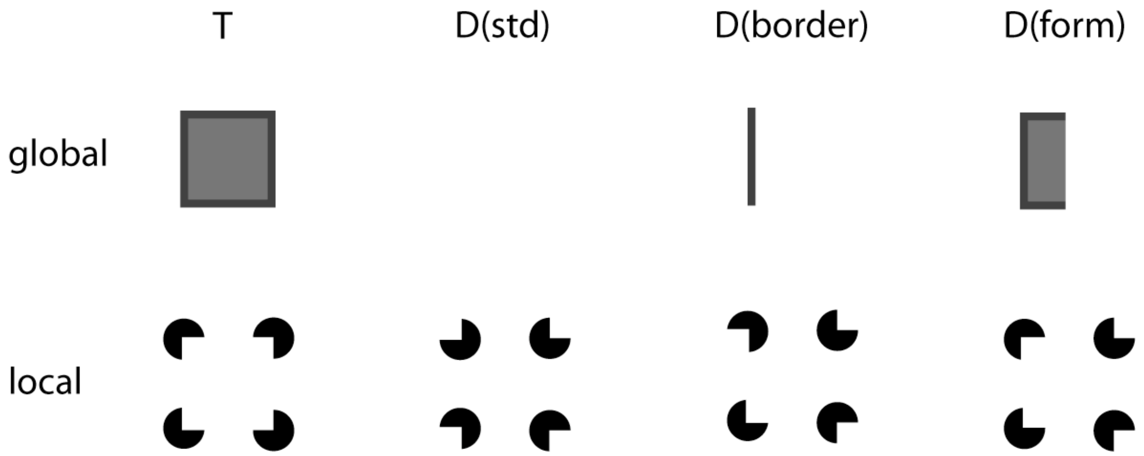

Figure 6 Examples of local inducer configurations and corresponding global stimulus expressions of the target (T) Kanizsa figure and (standard, border and form) distracters (D) employed in experiments described in Chapter II.

In addition, search performance was compared to subjective ratings of figural goodness. The results from Experiments 1 and 2 indicated that global form information but not the surrounding border influences target detection at parallel stages and can be related to subjective measures of figural goodness. In addition, Experiment 3 demonstrated that local information is only encoded if target identity lacks corresponding global attributes. Finally, Experiment 4 demonstrated that interference based on global form could be attributed to a process that gradually interferes with successful target detection.

Chapter III: Chapter II has shown that visual search for an illusory target configuration is susceptible to interfering form information while neglecting information about contours. Consequently, in Chapter III, the physiological basis for this global form interference effect was investigated by recording event-related potentials elicited from contour- and surface-based distracter interactions with detection of a target Kanizsa figure. Interestingly, in Experiment 5, variations of search performance resulting from distracter interference revealed specific variations within the N2pc component in the lateral occipital complex (LOC), which is interpreted as reflecting the allocation of attentional resources upon a selected target (Luck & Hillyard, 1994a; Eimer, 1996). Consequently, this indicates that target selection is based upon form information. In accordance with this outcome, LOC has been interpreted as playing an important role for the extraction of salient regions to guide target selection (Stanley & Rubin, 2003).

Chapter IV: The evidence presented so far indicates that visual search for an illusory figure depends largely on the specification of the illusory form (i.e. surface). Both behavioral and electrophysiological approaches indicate that surface information is processed with priority while information about the contour does not influence detection. Following this investigation of effects resulting from the specification of an emergent figure, Chapter IV describes experiments that investigate whether similar effects can also be found for configurations that are grouped on the basis of (local) closure and collinearity relations but without a corresponding (global) percept of an illusory square. As for Chapter II, in Chapter IV, visual search was employed to compare the efficiency of detecting a target upon varying sets of distracter configurations. Instead of Kanizsa squares, collinear line segments were used to form target squares and distracters exhibiting systematic variations to explore how closure and collinearity interfere with efficient target detection. Experiment 6 indicated no search interference for distracter configurations that exhibited ‘open’ forms. By contrast, ‘closed’ form distracters severely disrupted efficient search performance. In agreement with this finding, Experiments 7 and 8 demonstrate that closure between neighboring corner junctions determines the efficiency of search and can be regarded as a major contributor towards form detection.

Consequently, the effects reported may be considered in terms of general mechanisms supporting the rapid extraction of salient regions to guide search.

Chapter V: The evidence that was introduced in this report in Chapters II to IV investigated the conditions that critically affect ‘bottom-up’ processes in detecting a target configuration. To complement these outcomes, Chapter V investigated how ‘top-down’ information resulting from task specifications influences performance measures. Following previous investigations, detection of a target was compared to a task demanding the identification of a specific target configuration. Previous evidence from visual search indicates that both tasks are supported by sequential processing stages. In an initial stage, target detection is accomplished by parallel feature analysis. Subsequently, identification of the target is realized by a serial mechanism (Sagi & Julesz, 1985a; 1985b). Chapter V investigated this relation between detection and identification in displays that presented target Kanizsa figures embedded within variable sets of distracter configurations. Three experiments were performed. Experiment 9 was performed to obtain baseline measures for detection. A comparison of shape orientations in squares and diamonds replicated previous outcomes that demonstrated an effect of oblique stimulus presentations. These were found to be processed slower than cardinal stimulus orientations (see Purghe, 1989). Subsequently, Experiments 10 and 11 were performed to investigate variations of task instructions. Results indicated that salience determines whether detection and identification correspond to sequential or interacting processing stages. Inefficient performance resulted in sequential task ordering. By contrast, efficient performance depicted a dynamic interaction between task-related processes. Consequently, this outcome supports a conception of processing stages for detection and identification that are dynamically adjustable depending on the saliency of the target configuration.

Conclusion

The present work consists of four series of experiments conducted to investigate how object fragments are completed in visual search. In agreement with various other studies that investigated the role of grouping processes (i.e. Rensink & Enns, 1995), the outcomes presented here suggest that the basis for successful target detection relies on the integrated representation of object fragments forming a complete perceptual object. Depending on the specification of the target, different attributes of an object are preferred and consequently, registered with priority. For Kanizsa figures, the basis for search was determined at the level of a global form representation (Chapter II: Experiments 1, 2 and 4). By contrast, effective search for collinear groupings depended upon the extent to which closure integrated neighbouring stimulus fragments (Chapter IV). Finally, search for configurations that do not induce the integration of elements into a coherent whole depicted inefficient, slow search while performance relied on the local arrangement of single inducer elements (Chapter II: Experiment 3). Thus, for all three target types, the most salient attribute of a given target configuration was exploited to aid search effectivity. This outcome is consistent with the suggestion of a region-based scene segmentation process that determines salient regions within a given environment (Stanley & Rubin, 2003). Depending on the specification of the to-be-detected target arrangement, appropriate salient object attributes are considered for the guidance of search.

Support for this process of segmenting salient regions during search has also been found when investigating event-related potentials elicited from Kanizsa figure detection performance. Chapter III presented a variant of the search task in Experiment 1 (Chapter II) and compared how various attributes of a distracter influence search processes and associated changes in the event-related potential. The results replicated the previous (global) form interference effect and indicated that the successful suppression of the irrelevant distracter was reflected by amplitude difference in the N2pc component (240-340 ms) at occipito-parietal electrode positions. Given that this topography closely corresponds to other results that postulate a functional role for LOC in coding emergent surface characteristics (Murray et al. 2002; Stanley & Rubin, 2003), the current outcome suggests that target selection is mediated by similar mechanisms. Thus, N2 activations reported in Chapter III correlate with a shift of attention to the relevant target location. However, this N2-specific shift of attentional resources was biased by competing form information at irrelevant distracter locations. Thus, similarity between targets and distracters was directly reflected at the physiological level.

The finding that visual search for an illusory target configuration is susceptible to interfering form information while neglecting information about contours is also of importance when evaluating equivocal results from previous search experiments that employed Kanizsa figures (Davis & Driver, 1994; Gurnsey et al., 1996). Initial reports for efficient search for Kanizsa figures intended to relate these outcomes to activation patterns elicited in areas V1 and V2 in response to illusory contours (Davis & Driver, 1994). While subsequent results questioned this correspondence (Gurnsey et al., 1996), the current outcome shows that search performance interferes with form information and suggests that it is not the contour which is coded, but the corresponding surface (Chapter II) that could be related to filling-in mechanisms in area LOC (Chapter III).

Besides effects that have been reported in Chapters II and III for global illusory figures, a comparable target-distracter interference effect was also been documented for groupings defined by means of closure and collinearity (Chapter IV). Consequently, the registration of global form information in an illusory figure corresponds to closure between neighbouring segments within a collinear grouping. In line with other findings (Elder & Zucker, 1993; Kovács & Julesz, 1993; Donelly et al., 1991), this outcome suggests that closure can be regarded as a major contributor towards form detection.

Complementary to information provided through attributes that specifiy part-whole relations such as form or closure, detection performance for illusory figures and collinear groupings, has also been reported to vary as a function of stimulus orientation. Chapter V (Experiment 9) described a clear preference for horizontal and vertical shape orientations. Whereas search for square configurations could be performed independent from the number square distracters, diamond targets were sensitive to the number of diamond distracters presented concurrently with the target. In agreement with previous search studies that employed Kanizsa figures (Davis & Driver, 1994; Grabowecky & Treisman, 1989; Grabowecky, Yamada & Strode, 1997), this finding supports differences in processing of shape orientations for real (Appelle, 1972) and illusory figures (Purghe, 1989; Ehrenstein & Hamada, 1995). Whereas cardinal orientations are detected efficiently, oblique contours lead to inefficient performance.

Finally, in Chapter V, processing of illusory figures was analyzed as a function of task, that is, whether a target figure had to be detected or identified. Target detection and identification comprise two fundamental aspects of visual information processing. Evidence from visual search (Sagi & Julesz, 1985a; 1985b; Nothdurft, 2002) indicates that both tasks may be conceptualized within a system that engages sequential processing stages. In a first stage, early visual routines attempt to locate a target (detection). Subsequently, in a second stage of processing, the detected target is analyzed to recognize the specific object (identification). This strict separation of sequential processing stages is questioned from the results presented in Chapter V by employing Kanizsa figure target and distracter configurations. Results from two experiments that compared detection and identification indicate that the separation of processing stages depends upon baseline levels of performance. For inefficient performance, a sequential task ordering could be observed. By contrast, efficient performance depicted a dynamic interaction of related processing stages. Consequerntly, this outcome supports a conception of procesing stages that are dynamically adjustable depending on the saliency of the target configuration (see Di Lollo, Kawahara, Zuvic & Visser, 2001).

Taken together, a range of results presented in four sections of this work suggests that figural completion relies on complex operations performed at various levels of stimulus processing (see Palmer, Nelson, Brooks, 2003). On one hand configural factors that determine part-whole relations between elements determine which aspect of a given scene will capture attention. Evidence from illusory figures and collinear groupings was presented that suggests specific processes determining search efficiency. On the other hand, perceptual processes remain susceptible to task requirements allowing a dynamic configuration to obtain an optimum in performance.

CHAPTER II

The contrasting impact of form and inducer similarity on Kanizsa figure detection

Abstract

Studies on the involvement of contour completions in search for illusory figures have so far reported equivocal results. In the current study, this issue was addressed by investigating specifically at which level object attributes of a Kanizsa figure influence search. A paradigm was employed that investigated how global and local factors in distracters influence target detection, thereby, depicting a selective involvement of multi-level processing upon search. Four experiments demonstrate that global form information but not the surrounding border influences target detection at parallel stages and can be related to subjective measures of figural goodness. By contrast, local information is only encoded if target identity lacks corresponding global attributes. It is concluded that similarity acts as a major determinant of search but depends on the particular level (local/global) coding the target.

Introduction

When perceiving objects in the natural environment, occluding surfaces and non-optimal viewing conditions often allow only for a partial detection of object features. Nevertheless, the visual system is capable of producing an unambiguous representation of the visual world. In order to 'see' the world in a meaningful way the visual system has not only to discriminate the separate features of objects, but also to integrate the separate parts of an object into a single percept. The existence of such integrative processes in the human visual system is demonstrated by the phenomenon of illusory figure perception (i.e. Spillmann & Dresp, 1995). One famous example, the Kanizsa figures (Kanizsa, 1955; see Figure 1a for an example) illustrate the ability of the visual system to combine separate features into coherent wholes in the absence of luminance-defined borders. Objectively, this arrangement of elements depicts only four semicircles that are physically present. However, our visual system interprets this configuration as a square occluding four disks. Phenomenally, this emergent figure appears with a central bright region surrounded by sharp boundaries that depict depth stratification.

From a psychological perspective, the perception of illusory figures has traditionally been attributed to higher-level operations achieving object completion (e.g. Gregory 1972; Rock & Anson 1979; Pritchard & Warm, 1983). In this view, the perception and completion of illusory figures can be seen as the result of cognitive and inferential hypotheses concerned with interpreting the physical environment in an attempt to obtain a consistent representation of a visual scene. Contrary to this conception, illusory figures have also been regareded as a product of data-driven reflexive mechanisms located early in the visual processing pathway. Support for this claim has been demonstrated in neurophysiological studies that show specific responses to illusory contours in early visual areas V1 and V2 (von der Heydt, Peterhans & Baumgartner, 1984; Peterhans & von der Heydt, 1991; Lee & Nguyen, 2001).

Attempts to establish a psychophysical case in support of the idea that illusory figure formation is based upon low-level processing has so far lead to equivocal results. A series of studies employed visual search techniques (Treisman & Gelade, 1980) to investigate whether an illusory contour stimulus can be detected efficiently. According to this approach, an illusory figure is defined as the target configuration and is to be detected as fast as possible amongst a set of distracter configurations that constitute the same inducer elements, however, this time rearranged so as not to form an illusory figure (see Figure 1b for an example display). Applying this paradigm, one study could show that illusory contours from offset gratings can be detected in parallel (Gurnsey, Humphrey & Kapitan, 1992). By contrast, a study by Grabowecky and Treisman (1989) reported that search for Kanizsa figures was dependent from the number of distracter items that are present simultaneously in the visual field. However, by carefully reconsidering this setup, Davis and Driver (1994) reported that an illusory Kanizsa figure could be detected in parallel if conditions for detection were made optimal. In a series of experiments, they demonstrated that a Kanizsa square could be searched for independent from the number of non-targets presented simultaneously in the visual field, providing a psychophysical correlate to the results from physiological studies (Peterhans & von der Heydt, 1991). Nevertheless, this accordance between different approaches was seriously questioned in a follow-up study (Gurnsey, Poirier & Gascon, 1996), demonstrating an independence of search from the presence or absence of an illusory contour in search displays. For example, search for Kanizsa square arrangements could be performed in parallel; by contrast, illusory contour stimuli as employed in physiological studies (von der Heydt et al., 1984) gave rise to serial self-terminating search. Finally, if observers were presented with square target and distracter arrangements composed of L-corner junctions (which do not induce illusory contours), target detection revealed to be based on parallel search. Thus, search efficiency clearly depended on factors other than the presence or absence of an illusory contour. In sum, the role of illusory figure processing in visual search remains unclear since factors other than illusory contour coding may have been responsible for discrepant findings.

Furthermore, a strict separation of dichotomous processing stages differentiating high-level from low-level processes in illusory figure perception has recently been questioned (Davis & Driver, 1998; see also Palmer, Brooks & Nelson, 2003). Rather, it is assumed that the illusory percept results from multiple stages of processing (i.e. Lesher, 1995) that would require a detailed characterization of specific critical processes themselves. Consequently, illusory figures cannot be regarded as an entity but result from a variety of computational steps that can be ascribed to independent processes of brightness enhancement, contour integration and depth segregation (i.e. Spillmann & Dresp, 1995). Therefore, focusing solely on a distinction between early and late processes might be misleading. Instead, an attempt in the current approach was made to identify specific processes coding object properties that are of major influence and serve as the basis of search.

In order to address the question which aspect of an illusory figure can be regarded as a defining attribute for search, a series of reaction time (RT) studies are introduced that intended to uncover critical processes for successful detection of an illusory Kanizsa figure. Previous studies (Grabowecky & Treisman, 1989; Davis & Driver, 1994; Gurnsey et al., 1996) aimed to demonstrate efficient performance in detection of an illusory figure defined as the target configuration. By contrast, in the present report the influence upon the efficiency of search was studied by comparing specific attributes of target and distracter configurations. Considering the example of a Kanizsa square in Figure 1a, two levels of organization can be defined that are important for the specification of object attributes (see Rauschenberger & Yantis, 2001). On one hand, at a local level the Kanizsa square comprises inducing elements ('pacmen') that correspond to the 'physical reality'. On the other hand, a global level of an object can be defined that comprises the emergence of an illusory square illustrating respective surface characteristics and corresponding borders that surround the global figure (Grossberg & Mingolla, 1985; 1987; Lesher, 1995, Spillmann & Dresp, 1995). Consequently, at least three object attributes can be distinguished: local inducers, global borders and global form (i.e. surface). In order to investigate which of these properties are predominantly processed, in the remainder of Chapter II, a series of visual search experiments will be described that systematically varied similarity aspects of targets and distracters. As has been shown (Duncan and Humphreys, 1989) the similarity relations between targets and distracter are a major determinant of search efficiency. Whereas a high target-distracter similarity would lead to inefficient performance, the contrary can be observed for a low similarity between target and distracters. Consequently, this relation was systematically explored in the current experiments with respects to each object attribute specified for global and local levels.

Following this rationale, Experiment 1 investigated the relevance of global borders and global form for efficient search performance. Systematic variations of border and form attributes in distracter configurations indicated that only the global form is coded in search. In extension to this finding, Experiment 2 was performed to further decompose the critical aspects of form for search. Specifications of form in Experiment 1 critically depended on the surrounding contours. To overcome this dependence in Experiment 2, surrounding contours were varied independently from the specification of a central surface. The results strengthened previous outcomes (Experiment 1) in showing that only the surface is critical for determining the efficiency of search whereas the surrounding contours did not contribute to this effect. Subsequently, and to complement this investigation of global influences, Experiment 3 focused on critical aspects of search at the local level by introducing a new target that is only defined in terms of local inducer configurations. The results from the experiment revealed that performance now completely switched showing determinants of search only at the level of the local inducers. Finally, Experiment 4 reassessed the underlying characteristic of the basic global form effect in showing that the performance deterioration described in Experiment 1 can be related to a system coding multiple objects without capacity limitations in parallel across the visual field. It is concluded that similarity between targets and distracters (see Duncan & Humphreys, 1989) is a major determinant for the efficiency of search. Depending on the definition of the target, those object attributes that dominate in coding target identity interfere most in visual processing.

EXPERIMENT 1

Experiment 1 sought to investigate the relative effects of distracter configurations exhibiting global form or border attributes upon detection of a target Kanizsa figure. In Experiment 1a observers were presented with search displays that either contained potentially conflicting global ‘form’ or ‘border’ distracters. The aim of this manipulation was to decide upon the interfering effect of both types of object attributes in detecting a target Kanizsa figure. In addition, Experiment 1b was performed to relate speeded (search) responses to phenomenal subjective impressions of figural goodness. This goal was approached by determining the subjective impression of figural goodness by means of a rating procedure classifying all stimulus arrangements employed in the experiment.

EXPERIMENT 1A

The experiment described in the following was comparable with those of Grabowecky and Treisman (1989), Davis and Driver (1994) and Gurnsey et al. (1996) in presenting observers with search displays that required a speeded response to indicate the presence or absence of a target Kanizsa figure upon varying sets of distracter configurations. However, the design differed from previous setups in applying systematic variations to the composition of distracter configurations. As can be seen in Figure 1a, the target stimulus (T) was a Kanizsa square that consisted of four aligned inducers to promote the emergence of a global object. In contrast, the distracter stimuli (D) were constructed from the same inducers, which were reoriented such that they did not afford a complete illusory figure. Variations in the arrangement of the distracter elements could afford either the partial emergence of a global form depicting a surface (Figure 1a, I) or a

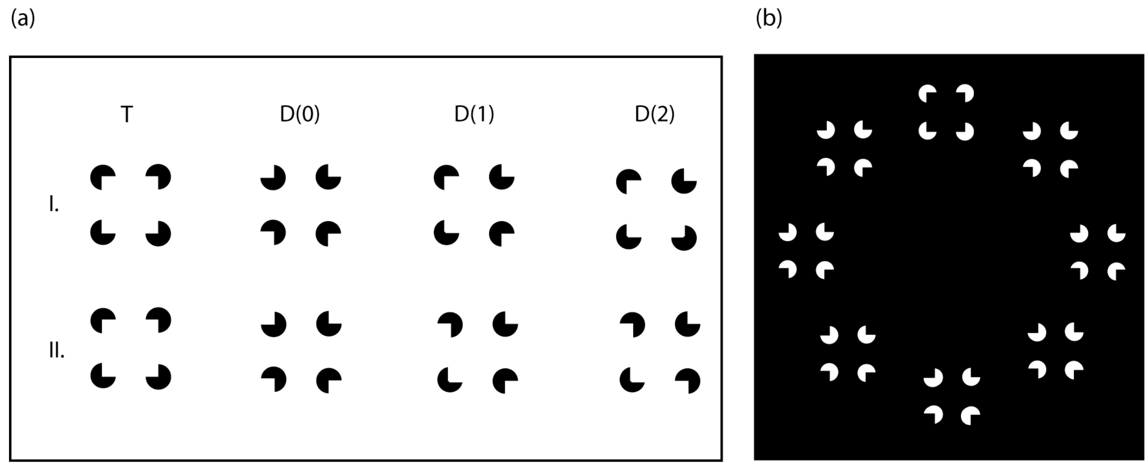

Figure 1 (a) Examples of the target Kanizsa square (T) and distracter stimuli (D) presented in Experiment 1. Distracters could be constructed from zero, one or two illusory contours (D(0) – D(2)) that could either induce a global form (I) or a global border (II). (b) Example of a target present display with 8 candidate groupings showing all possible stimulus locations for all different display sizes (see Methods).

global border that does not depict surface characteristics but maintained the illusory contour (Figure 1a, II). In both global border and global form conditions the number of defining illusory contours in the distracters was varied (D(0)-D(2), see Figure 1a) increasing the similarity of competing candidate arrangements that could interfere in the process of target detection. Accordingly, an interference of global border or global form distracters on target detection could address the question of whether search performance can be related to the computation of contour signals or the resulting emergent shape.

Methods

Participants: Eight paid observers (2 male, mean age = 27.1 years) with normal or corrected-to-normal visual acuity participated in the experiment for payment of 8 Euro per hour.

Stimuli: Stimuli were generated by an IBM-PC compatible computer and presented in dark white (1.83 cd m^{-2}) against a black (0.02 cd m^{-2}) background at eight locations arranged in a circle around the center of a 17-inch computer monitor at an eccentricity of 8.75° (see Figure 1b for an example). At a viewing distance of 55 cm, each candidate grouping (composed of four inducing elements with a diameter of 1°) subtended a viewing angle of 2.9 x 2.9°. As depicted in Figure 1a, the target (T) was defined as a Kanizsa square, whereas distracter groupings (D) were obtained by rotating inducer elements so that these could contain zero, one or two aligned illusory contours that either induced an emergent global form (Figure 1a, I) or supported the completion of global borders (Figure 1a, II). Each trial could contain 1, 2, 4 or 8 candidate groupings presented at random orientations, with a target Kanizsa figure present on 50 % of all trials. For display sizes smaller than 8 candidate groupings, stimuli were presented pseudo randomly at the 8 positions illustrated in Figure 1b with restrictions given display sizes of 2, for which candidate groupings were presented at diametrically opposite positions only and given display sizes of 4, for which candidate groupings were presented at every second position of the eight possible display locations.

Procedure: Each trial started with the presentation of a fixation cross for 500 ms at the center of the screen. The fixation cross was then immediately replaced by the search display to which observers responded with a speeded target absent/present response via mousekeys. Displays remained on-screen until a response was given. In case of an erroneous response or a time-out (after 2500 ms), feedback was given by a computer-generated tone and an alerting message presented for 500 ms at the center of the screen. Each trial was followed by an ISI of 500 ms.

The experiment consisted of 2 sessions with 12 blocks containing 80 trials each, resulting in 40 trials per experimental condition. Each session consisted of trials containing border or form groupings with separate blocks for each distracter type (D(0)-D(2)) to obtain solid measures for each stimulus condition without conflicting variations from inter-trial transitions. Blocks were administered in pseudo-random order on a subject-by-subject basis.

Results and Discussion

RT analysis: RTs on trials on which a response error (4.1 %) was made were removed from the RT data set prior to analysis. Visual inspection of the RT distribution revealed no pronounced positive skew, which would require the application of correction procedures. Figure 2 presents mean correct RTs and the percentage of errors as a function of display size for each distracter configuration in the global border and form condition (columns (a) and (b), respectively). In addition, both responses to global border and global form conditions were compared by means of two repeated-measures ANOVAs computed on the factors *target* (present, absent), display size (*ds*: 1, 2, 4, 8 elements) and illusory contours (*ic*: 0, 1, 2 contours).

The ANOVA conducted on stimuli that induced a global border revealed all main effects [target: $F_{(1, 7)} = 20.08$, $p < .01$; ds: $F_{(3, 21)} = 17.35$, $p < .001$; ic: $F_{(2, 14)} = 17.11$, $p < .001$] and interactions with display size to be significant [target*ds: $F_{(3, 119)} = 13.58$, $p < .001$; ds*ic: $F_{(6, 119)} = 6.21$, $p < .001$]. By contrast, analysis of global form stimuli resulted in a different outcome.

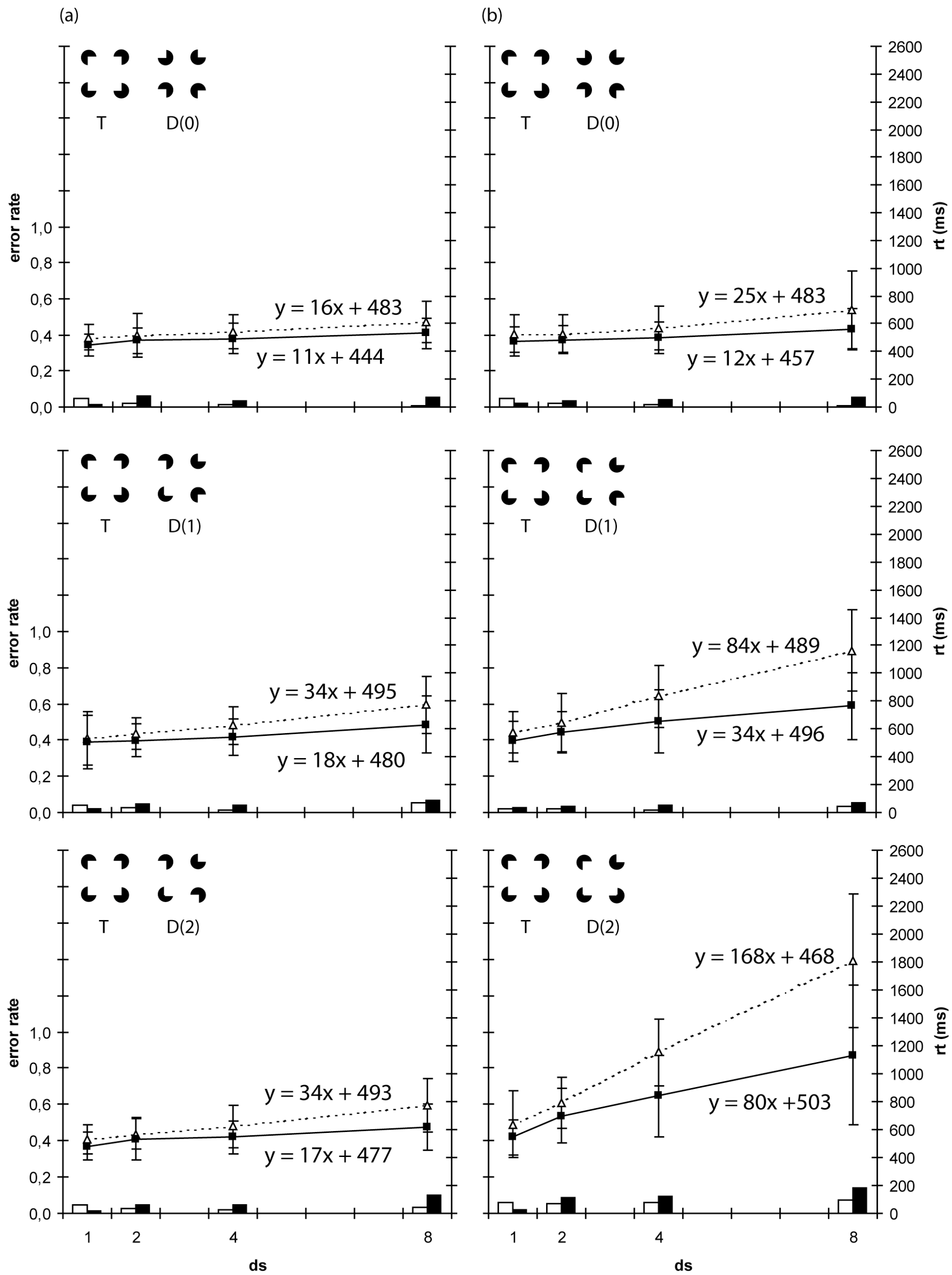

Figure 2 Mean RTs, SDs and associated error rates in Experiment 1a as a function of display size for trials containing global borders (a, left column) and global form information (b, right column) for zero, one or two illusory contour distracters, presented in top, middle and bottom graphs, respectively. Each graph shows a prototype target (T) and an example of a distracter grouping (D) and plots RTs, SDs and error rates separately for target absent (dotted line, white bars) and target present trials (solid line, black bars). In addition, the function for the best fitting straight line is given for each reaction time distribution depicting slopes and base rate RTs.

For global form stimuli, all main effects [target: $F_{(1, 7)} = 87.35$, $p < .001$; ds: $F_{(3, 21)} = 216.90$, $p < .001$; ic: $F_{(2, 14)} = 141.93$, $p < .001$], two-way interactions [target*ds: $F_{(3, 119)} = 82.52$, $p < .001$; target*ic: $F_{(2, 119)} = 52.40$, $p < .001$; ds*ic: $F_{(6, 119)} = 120.04$, $p < .001$] and the three-way interaction were significant [target*ds*ic: $F_{(6, 119)} = 14.91$, $p < .001$] illustrating an increase in RTs with improvements in the specification of surface information in distracters (see Figure 2b). Thus, search performance markedly decreased leading to steeper display size x target functions with the emergence of global form distracter specifications. By contrast, no significant three-way interaction (and a corresponding performance decrease) was observable for distracters that contained global borders (see Figure 2a).

Error analysis: Arcsine-transformed error rates were analyzed by means of identical repeated-measures ANOVAs to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs.

Analysis of the error data for global border stimulus configurations revealed the target and display size main effects were significant [target: $F_{(1, 7)} = 6.57$, $p < .05$; ds: $F_{(3, 21)} = 3.23$, $p < .05$] as were their interaction [target*ds: $F_{(3, 119)} = 11.18$, $p < .001$]. Error rates increased with display size and were more pronounced for target absent conditions. Similarly, errors for global form configurations significantly increased with display size [ds: $F_{(3, 21)} = 3.49$, $p < .05$], while display size again interacted with target [target*ds: $F_{(3, 119)} = 6.12$, $p < .001$]. Finally, the form-specific RT increase illustrated above also manifested in a significant main effect of illusory contours [ic: $F_{(2, 14)} = 29.90$, $p < .001$] depicting increased error rates with an increase in the specification of global form. Thus, both RT data and error rates showed similar trends indicating clear performance differences between global form and global border conditions. No other significant effects were obtained.

In sum, the results of Experiment 1a show a contrasting pattern of performance that suggests the effects of global form and global border stimuli should be differentiated. Presenting observers with displays that contain virtual line (i.e. global border) continuations in distracter groupings does not critically affect the efficiency of target detection. As can be seen in Figure 2a, the introduction of one or two illusory borders in distracter arrangements does not impair performance measures; minor changes in the slope of the search function may be attributable to increased noise in the displays due to reduced similarity between distracters (Duncan & Humphreys, 1989). Consistent with this observation, no significant three-way interaction arises from the RT analysis. By contrast, the presence of global form distracters deteriorated performance dramatically. As shown in Figure 2b, the presentation of form information supported by a single illusory contour in distracter groupings (D(1)) impairs search performance and leads to search rates that are approximately 3 times higher than corresponding D(0) distracter groupings. Adding a second illusory contour that specifices the emergence of form in distracter groupings (D(2)), again impairs performance and disrupts performance even further (with search rates that are approximately 6 times higher than performance with D(0) distracter arrangements). Consistent with this observation, statistical analyses reveal a significant three-way interaction in the analysis of the RT responses confirming the performance deterioration for distracter configurations that promote the emergence of global form.

Taken together, this difference in performance between global border and form configurations demonstrates that it is not the illusory contour in isolation (i.e. the ‘global border’) but the resulting emergent form that is coded in the search process. In this respect, illusory contours may only affect performance based on similarity-dependant competition if the resulting surface is figurally relevant.

EXPERIMENT 1B

A subsequent experiment was carried out to determine, whether variations in global stimulus parameters and the resulting variations in performance measures (RTs and error rates) coincide with the subjective impression of figural ‘goodness’. Accordingly, in Experiment 1b participants were asked to rate the quality of the illusory percept (see Shipley & Kellman, 1992) for all stimulus combinations presented in the previous search displays.

Methods

This experiment was identical to Experiment 1a, except as reported here. The same 8 observers participated in this experiment. Stimuli were identical to the previous search experiment, however, only one candidate grouping was presented on each trial at a fixed position at the top location of the predefined display shown in Figure1b. For each candidate grouping the observers were instructed to subjectively rate the stimulus according to the goodness of figural grouping on a five-point scale ranging from 1 (low goodness) to 5 (high goodness). Non-speeded responses were collected via keyboard. The rating experiment consisted of 3 blocks containing 80 trials each, resulting in 40 trials per experimental condition. All candidate groupings were presented in random order.

Results & Discussion

Figure 3a presents the mean ratings (and associated standard deviations) for each stimulus configuration. In addition, t-tests were computed to statistically compare rating scores. As illustrated in Figure 3a, only global form configurations exhibited significant differences, whereas no statistical difference was obtained for the comparison of global border configurations.

In a subsequent step, rating performance was compared to the slope of the target absent search functions in Experiment 1a. This measure was chosen as an indicator to capture search characteristics for each possible stimulus configuration. Since target absent trials are not confounded with a second stimulus (the target) these conditions were regarded as 'representatives' for each stimulus configuration. This comparison of search performance measures with subjective ratings was characterized by a substantial linear correlation ($r^2 = .92$, $p < .01$) as illustrated by the dotted line in Figure 3b. However, a linear relationship might not provide the best description for the scatter of data points. Instead, a better approximation of this distribution could be fitted by a non-linear function accounting even for a larger proportion of variance ($r^2 = .99$, $p < .001$) and exhibiting an exponential increase of slopes with an increase in subjective ratings. As can be seen in Figure 3b, this distribution of responses corresponds to the qualitative switch between global border and form configurations. Thus, subjective ratings account for

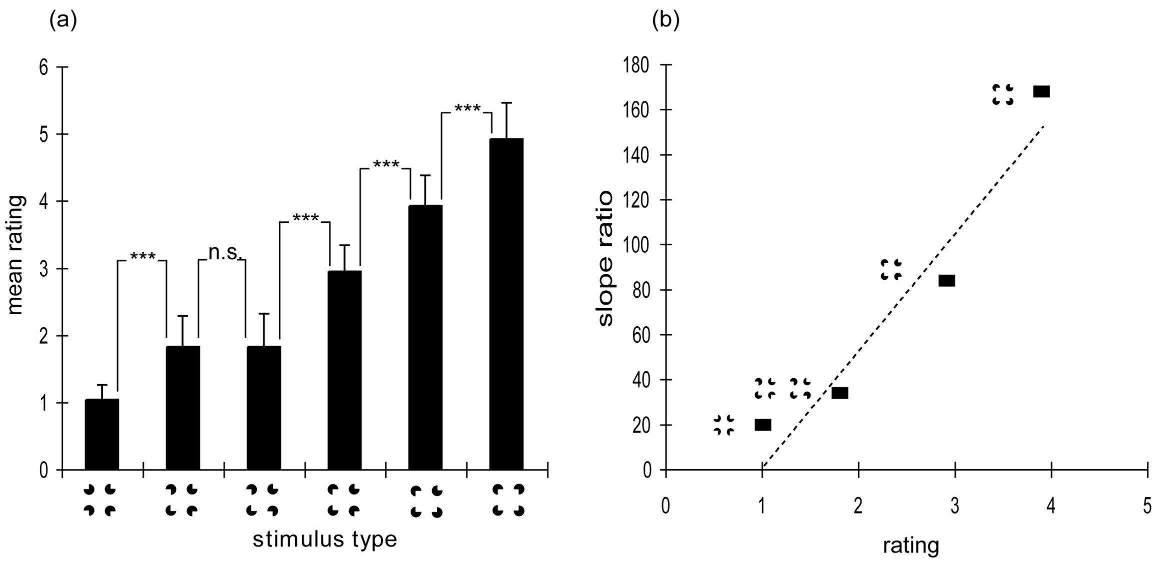

Figure 3 (a) Mean subjective figural goodness ratings (and associated SDs) as a function of stimulus type, assessed on a five-point rating scale in Experiment 1b. High ratings denote a high impression of figural goodness. ***Indicates the highly significant difference ($p < .001$) in subjective ratings between stimulus types that differ in terms of their global form. No significant differences (n.s.) were found when comparing global border groupings. (b) Mean subjective ratings (Experiment 1b) as a function of mean search rates in target absent trials (Experiment 1a) for all possible stimulus types. In addition, the illustrated best fitting linear approximation ($r^2 = .92$, $p < .01$) depicts an increase in slopes with increases in subjective ratings.

differences in the global form but do not account for differences in global border configurations.

To summarize, Experiment 1b shows that grouping stimuli were rated on the strength of the degree of closure afforded by the collinear organization of the corner junction elements. The highest rating score was obtained for the completed Kanizsa (target) square. In comparison, all other (distracter) stimuli that did not exhibit comparable figural closure were labeled with lower scores. Interestingly, different ratings were only obtained for global form stimuli, whereas groupings that supported global borders were not statistically distinguishable. In addition, the relationship between mean search rates and corresponding figural ratings suggests that the quality of figural grouping could account for a substantial proportion of variance in target search performance.

EXPERIMENT 2

Experiment 1 illustrates that both search performance measures and subjective judgments of figural goodness are influenced by the emergent form. However, in the experiment global form distracters were always defined in terms of the contours that surround the critical region. Consequently no conclusions can be drawn with respects to how the emergence of surface characteristics can be related to the computation of a contour surrounding the critical region, since both components were always varied together. As a result of this, no possibility is given to evaluate the impact of form and border independent from another. On this basis Experiment 2 sought to dissociate both factors by varying the surrounding contours while maintaining a specific definition of the emergent form. Experiment 2a again asked observers to detect a Kanizsa target square amongst varying distracters whereas Experiment 2b employed a figural rating procedure to estimate the subjective figural goodness for all stimulus configurations.

EXPERIMENT 2A

Experiment 2a was identical to Experiment 1a, except that global border distracters were manipulated such that contour completion could be varied while controlling the presence of a central surface (see examples in Figure 4, II). This central

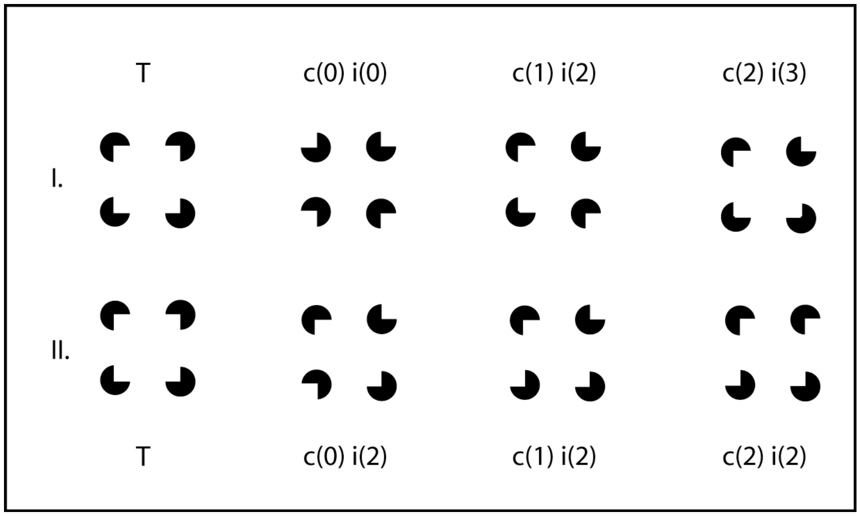

Figure 4 Examples of the target Kanizsa square (T) and distracter configurations presented in Experiment 2. Distracters could contain zero, one or two illusory contours (c(0) – c(2)) and zero, two or three inducers that faced inwards to generate a partial emergent shape (i(0) – i (3)). The upper column (I) depicts stimuli from the global form condition that was contrasted with the global outline condition controlling the emergence of surface characteristics (II).

surface was composed from two inwards-oriented inducers that were placed on a diagonal. In addition, contour completions were varied along the vertical continuations of the configuration independent from the surface definition. Performance for these distracter configurations (referred to hereafter as the 'global outline' condition) was again compared to global form distracters as in Experiment 1a. (see Figure 4, I).

Methods

This experiment was identical to Experiment 1a, except that the global border condition was replaced by a global outline condition. Stimulus configurations for global outline distracters were designed such that a central emergent shape resulted from two inward-facing inducers elements placed on a diagonal while contour specifications were varied from zero through one to two along the vertical continuations (outlines) of each configuration (see Figure 4, II). Eight paid observers (3 male, mean age = 26.1 years) with normal or corrected-normal vision participated in the experiment. All other details were identical to the procedure described in the methods section of Experiment 1a.

Results and Discussion

RT analysis: As with Experiment 1, for Experiment 2 RTs on trials on which a response error (3.1 %) was made were removed from the RT data set prior to analysis. Again, visual inspection of the RT distribution revealed no pronounced positive skew, therefore, no corrections were applied. Figure 5 presents mean correct RTs and error rates as a function of display size for each distracter configuration in the global form and global outline condition (columns (a) and (b), respectively). Responses to form and outline configurations were compared by means of repeated-measures ANOVAs computed on the factors *target* (present, absent), display size (*ds*: 1, 2, 4, 8 elements) and illusory contours (*ic*: 0, 1, 2 contours).

The RT analysis of global outline configurations showed a significant outcome for the main effects of target and display size [target: $F_{(1, 7)} = 56.72$, $p < .001$; ds: $F_{(3, 21)} = 27.35$, $p < .001$]. In addition, the factor target interacted significantly with other factors [target*ds: $F_{(3, 119)} = 90.78$, $p < .001$; target*ic: $F_{(2, 119)} = 4.43$, $p < .05$]. By contrast, the RT analysis of global form configurations resulted in a different outcome replicating Experiment 1a. All main effects, [target: $F_{(1, 7)} = 100.07$, $p < .001$; ds: $F_{(3, 21)} = 70.83$, $p < .001$; ic: $F_{(2, 14)} = 110.71$, $p < .001$] two-way interactions [target*ds: $F_{(3, 119)} = 123.21$, $p < .001$; target*ic: $F_{(2, 119)} = 42.74$, $p < .001$; ds*ic: $F_{(6, 119)} = 91.48$, $p < .001$] and the three-

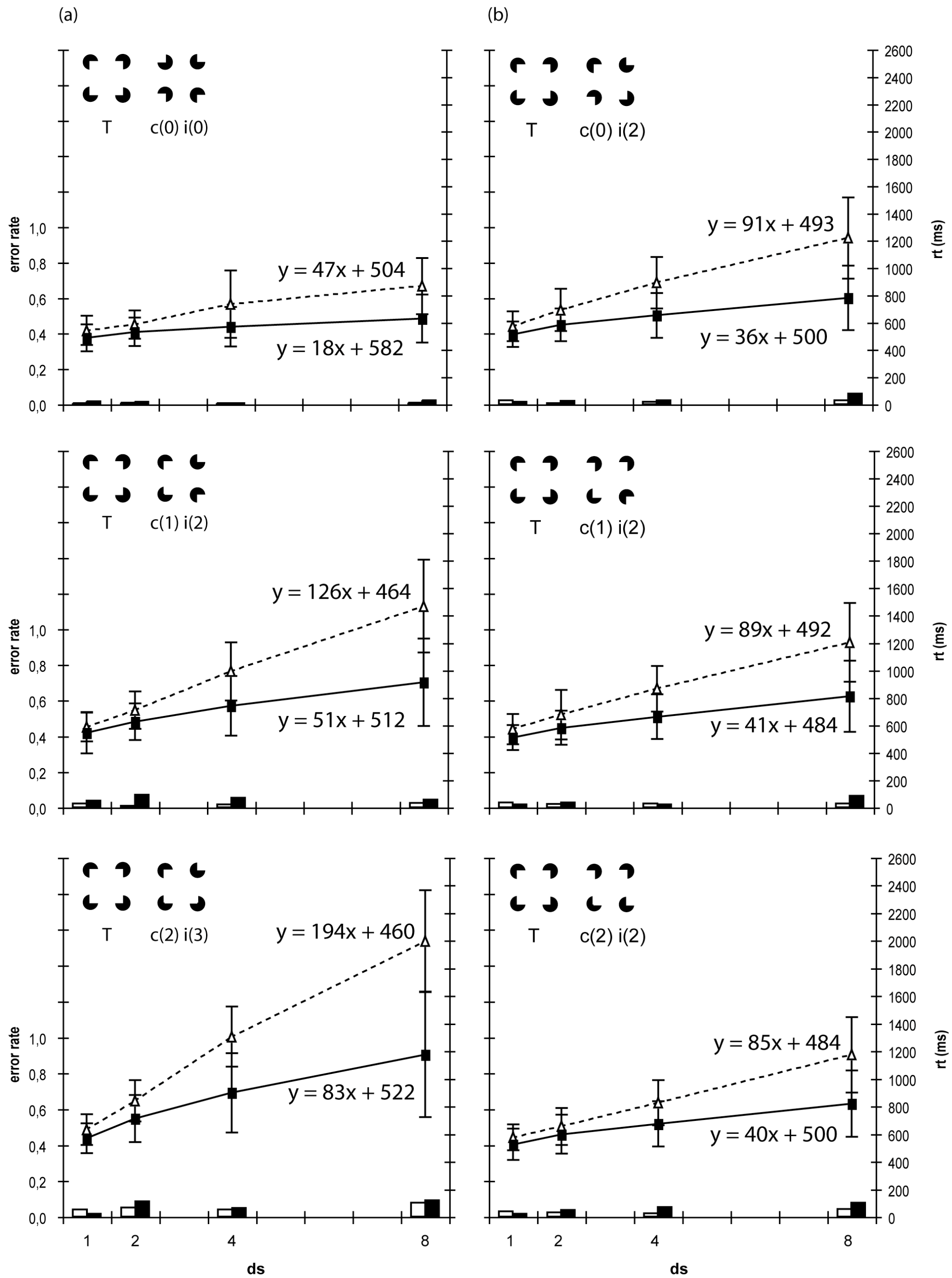

Figure 5 Mean RTs, SDs and associated error rates in Experiment 2a as a function of display size for the global form (a, left column) and global outline condition (b, right column). Zero, one or two illusory contour distracters are presented in top, middle and bottom graphs, respectively. Each graph shows a prototype target (T) and an example of a distracter grouping coding the number of contours (c) and inward facing inducers (i). RTs, SDs and error rates are plotted separately for target absent (dotted line, white bars) and target present trials (solid line, black bars). In addition, linear functions are given for each RT distribution depicting slopes and base rates.

way interaction were significant [target*ds*ic: $F_{(6, 119)} = 13.81$, $p < .001$]. As in Experiment 1a, an increase in the specification of the global form of the distracters led to slower responses with steeper display size x target functions. By contrast, global outline distracters showed no modulation with an increase in the number of contours but exhibited a consistent performance level for all identical specifications of the central emergent shape (compare all performance patterns in Figure 5 where the emergent form is composed from 2 inward-pointing distracters [i(2)]). Consequently, it can be concluded that contour information does not influence search efficiency.

Error Analysis: As in Experiment 1, arcsine-transformed error data were analyzed by means of identical repeated-measures ANOVA to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs. This analysis revealed for global outline configurations significant main effects of display size and illusory contours [ds: $F_{(3, 21)} = 3.64$, $p < .05$; ic: $F_{(2, 14)} = 8.94$, $p < .01$] and a significant interaction between target and display size [target*ds: $F_{(3, 119)} = 6.39$, $p < .001$]. In comparison to this pattern of results, error rates for global form configurations showed similar main effects [ds: $F_{(3, 21)} = 5.95$, $p < .01$; ic: $F_{(2, 14)} = 23.19$, $p < .001$] but dissimilar interactions of illusory contours with target and display size [target*ic: $F_{(2, 119)} = 4.29$, $p < .05$; ds*ic: $F_{(6, 119)} = 3.28$, $p < .01$]. Taken together, both RT data and error rates illustrate consistently that performance is influenced by contour information only if it corresponds to the related specification of emergent form. No other significant effects were obtained.

To summarize, Experiment 2a replicated the results obtained for Experiment 1a in showing that emergent form is a critical determinant of search efficiency. However, in extension to this finding, the introduction of global outline distracters indicates that emergent shape is independent from the contours that define the surrounding boundaries. As illustrated in Figure 5b, search performance remains equivalent across variations in the number of contours but is influenced solely by attributes defining the emergent form. All global outline distracters exhibit a deterioration of performance comparable to the global form configuration with a central emergent shape defined by two inward-facing inducer elements (labelled i=2, see Figure 5). In accordance with this finding, the RT analysis showed a non-significant three-way interaction for stimulus configurations with identical emergent shapes but a highly significant outcome when emergent shapes differed. Thus, this outcome provides evidence for the independence of surfaces from their surrounding contours. From a theoretical perspective, this outcome may be interpreted as empirical support for models of figural completion that assume shape processing to proceed from the surface to its boundaries and not vice versa (see Stanley & Rubin, 2003).

EXPERIMENT 2B

Complementary to Experiment 1b, this second part of Experiment 2 again employed a rating procedure to quantify the subjective impression for all stimulus configurations employed in the search experiment. This procedure permitted a comparison of subjective ratings with search performance patterns.

Methods

The experiment was identical to Experiment 1b, except that stimulus configurations were adjusted to the current version of the search Experiment 2a (see Figure 4 for examples). All eight observers had previously participated in Experiment 2a.

Results & Discussion

Figure 6a presents mean rating scores (and associated standard deviations) for each global form and global outline stimulus configuration employed for Experiment 2a. In addition, t-tests were computed to statistically compare rating scores. As illustrated in Figure 6a, differences between stimulus configurations were only evident for stimuli that differed on the basis of the emergent form defined through inward-facing inducer elements. Stimulus configurations that were identical in this parameter resulted in non-significant differences.

As for the previous experiment, rating scores were contrasted with the slope of target absent search functions in Experiment 2a, to compare performance measures for both experiments. This comparison of search and rating measures again resulted in a clear effect as illustrated in Figure 6b. As can be seen, stimuli with similar definitions of form clustered whereas differences in the form specification were evident for both measures. Statistical support for this relationship was again supported by a substantial linear correlation ($r^2 = .90$, $p < .01$). Thus, both measures displayed comparable stimulus dependant variation.

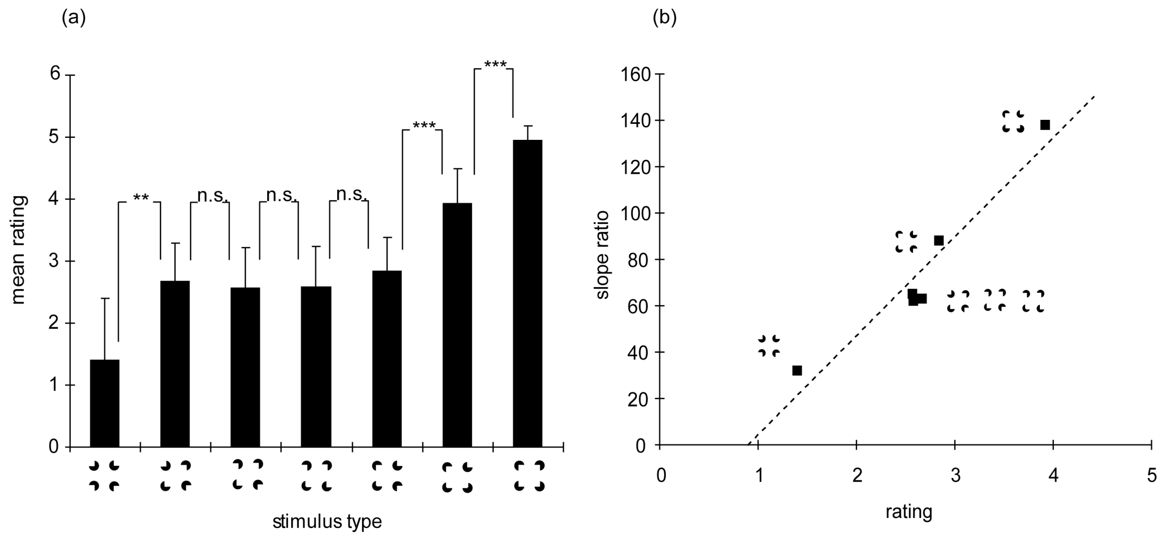

Figure 6 (a) Mean subjective figural goodness ratings (and associated SDs) as a function of stimulus type for Experiment 2b. High ratings denote a high impression of figural goodness. *** and ** indicate the highly significant differences ($p < .001$ and $p < .01$, respectively) in subjective ratings between stimulus types. No significant differences (n.s.) were found between configurations that were identical with regards to the specification of an emergent shape. (b) Mean subjective ratings (Experiment 2b) as a function of mean search rates in target absent trials (Experiment 2a) for all possible stimulus types. In addition, the illustrated best fitting linear approximation ($r^2 = .90$, $p < .01$) depicts the increase in slopes with increases in subjective ratings.

Taken together, the subjective measures of figural goodness revealed for the current experiment a clear relationship to the definition of a central emergent form. Whereas contour information was mostly neglected, the surface specification was a main factor for goodness judgments. Accordingly, rating performance again displayed a clear relationship to the efficiency of search. Both measures resulted in comparable performance distributions. Thus, both Experiments 2a and 2b offer strong support for the claim that emergent form but not the illusory contour plays a central role in processing. Furthermore, the outcome shows that form is not related to the absence or presence of an illusory contour. Therefore, a relationship between both processes could best be explained by a system that incorporates surface information with priority and defines specific attributes such as the contour only subsequently (see Stanley & Rubin, 2003).

EXPERIMENT 3

Experiments 1 and 2 show that search for illusory figures is determined by the presence or absence of emergent global form information extracted by the visual system. The results demonstrated that the similarity between targets and distracters interferes at the global level coding surface information and leads to inefficient performance with prolonged response latencies and increased error rates. Thus, these experiments show that search may be hindered by bound or completed forms which suggests search to proceed at the level of 'global' (i.e. illusory/emergent) rather than 'local' stimulus representations. As has been suggested, this global level of representation is generally held to be the basis upon which search proceeds whereas a local level is believed not to influence search even if it were beneficial to do so (i.e. He & Nakayama, 1992; Rensink & Enns, 1998; Davis & Driver, 1998; Rauschenberger & Yantis, 2001). This 'global precedence' hypothesis was tested in Experiment 3 by introducing a novel target configuration that is coded only at the local level of the inducer elements. Observers were presented with search displays in which a 'non-square' was the target. In addition, distracters were presented that varied the similarity relations to the target at the level of local inducers. However, concurrently with a reduction in local target-distractor similarity the strength of a global emergent form increased (see Figure 7a) permitting an examination of critical levels for search efficiency when the target is represented at local levels only. In addition, Experiment 3b again employed a rating procedure to estimate the subjective impressions of figural goodness for all stimulus configurations. Finally, Experiment 3c was performed as a control of similarity measures between distracter configurations (compare Figures 7b and 7c and details below).

EXPERIMENT 3A

The experiments presented here have so far investigated the role of global representations for search performance. By contrast, in Experiment 3a the target configuration was defined at the local level. Observers were now instructed to search for a target non-square (Figure 7a, T) among distracter configurations that varied local similarity relations to the target. The corollary of decreasing target-distracter similarity was an increase in the specification of the distracters as an illusory square, with maximally dissimilar distracters being optimally formed Kanizsa squares (see Figure 7a, i(1) – i(4) distracters). Given this modification, the role of global and local levels of representation where investigated for a target configuration represented only at local levels.

Methods

The experiment was in principle identical to the previous search experiments; except that the target was now defined as a non-square with inducing elements rotated outwards by 180 degrees (see Figure 7a, T) resulting in a stimulus representation at a local level. Distracters were varied comparable to the previous experiments, however, this time in relation to the new target configuration. Thus, a distracter configuration could be designed from 0-3 inducing elements that would face outwards as for the target configuration. Consequently, 1-4 inducing elements could be oriented inwards such that they resulted in a more or less completed (global) Kanizsa square (see Figure 7a, i(1) – i(4) distracters). Eight paid observers (3 male, mean age: 26.2 years) with normal or corrected-normal visual acuity participated in the experiment. In total, each observer completed two sessions with 8 blocks containing 80 trials each, resulting in 40 trials per experimental condition. All other details of the experiment were identical to the procedure described for Experiment 1a.

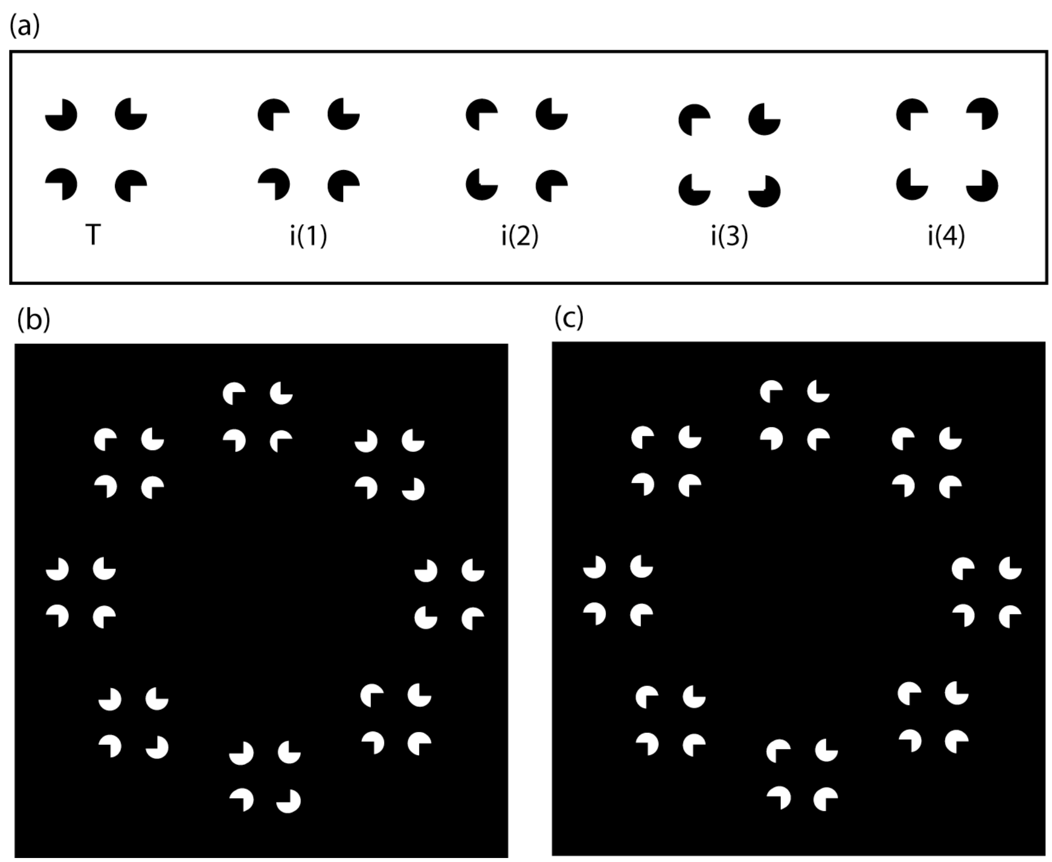

Figure 7 (a) Examples of the ‘non-square’ target configuration (T) and distracters presented in Experiment 3. Distracters could contain one to four inducers that faced inwards increasing the specification of the global form (i(1)-i(4)). Shown in (b) is an example target present display with 8 candidate groupings containing i(1)-distracters as in Experiment 3a. By contrast, the same display would be presented to observers in Experiment 3c but this time with a uniform orientation of distracters (c).

Results & Discussion

RT analysis: As with Experiment 1, for Experiment 3a RTs on trials on which a response error (4.6 %) was made were removed from the RT data set prior to analysis. In addition, visual inspection of the RT distribution revealed no pronounced positive skew which would require the application of correction procedures. Figure 8 presents mean correct RTs and error percentages as a function of display size separately for each of the four possible distracter types. RTs were compared by means of a repeated-measures ANOVA computed on the factors *target* (present, absent), display size (*ds*: 1, 2, 4, 8 elements) and distracter type coded as a function of the number of inducers facing inwards (*in*: 1, 2, 3, 4 inwards-oriented inducers).

RT analysis revealed significant main effects [target: $F_{(1, 7)} = 104.79$, $p < .001$; ds: $F_{(3, 21)} = 108.35$, $p < .001$; in: $F_{(3, 21)} = 125.21$, $p < .001$], significant two-way interactions [target*ds: $F_{(3, 168)} = 132.71$, $p < .001$; target*in: $F_{(3, 168)} = 29.53$, $p < .001$; ds*in: $F_{(9, 168)} = 105.86$, $p < .001$] and a significant three-way interaction [target*ds*in: $F_{(9, 168)} = 6.37$, $p < .001$]. The three-way interaction indicates that search performance (expressed by target x display size functions) decreased markedly with increases in local target-distracter similarity.

Error Analysis: As in Experiment 1, arcsine-transformed error data were analyzed by means of identical repeated-measures ANOVA to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs. As for the RTs, all main effects [target: $F_{(1, 7)} = 9.96$, $p < .05$; ds: $F_{(3, 21)} = 14.42$, $p < .001$; in: $F_{(3, 21)} = 5.44$, $p < .01$], two-way interactions [target*ds: $F_{(3, 168)} = 7.58$, $p < .001$; target*in: $F_{(3, 168)} = 4.24$, $p < .01$; ds*in: $F_{(9, 168)} =$

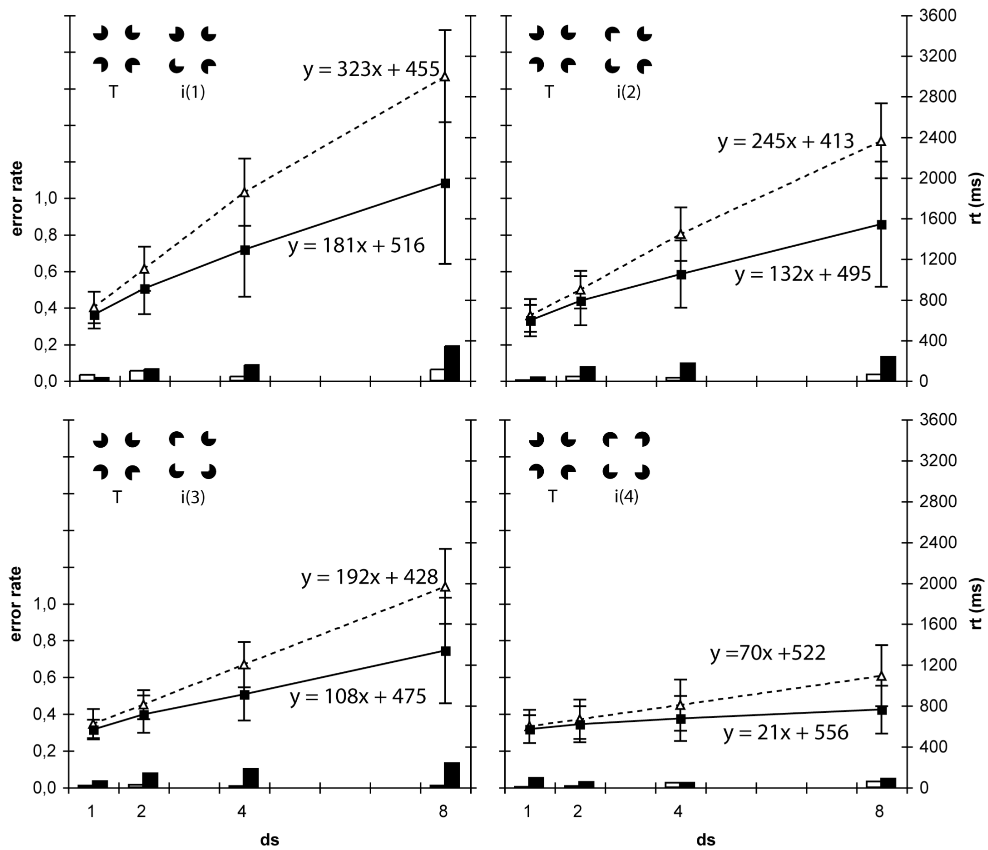

Figure 8 Mean RTs, SDs and associated error rates in Experiment 3a as a function of display size. Each graph plots a prototype target (T) and an example of a distracter grouping coding the number of inward facing inducers (i). RTs, SDs and error rates are plotted separately for target absent (dotted line, white bars) and target present trials (solid line, black bars). In addition, linear functions are given for each RT distribution depicting slopes and base rates.

2.18, $p < .05$] and the three-way interaction were significant [target*ds*in: $F_{(9, 168)} = 2.31$, $p < .05$]. Taken together, this pattern of results is consistent with the RT data described above in showing increased error rates with an increase in local target-distracter similarity.

In sum, Experiment 3a demonstrated that the primary source of search for a non-square can be related to local similarity relations between targets and distracters (see

Duncan & Humphreys, 1989). Response latencies and error rates were determined by similarity aspects related to the inducer elements themselves. Presenting observers with a non-square target led to greater search impairments if local attributes of the distracter were more similar to local attributes of the target. This impairment resulted in extremely steep slopes that suggest search performance to be dominated at the local level with each inducer element representing a single unit. Consequently, not the global emergent shape may be regarded as the basis of search, but rather each inducing element, leading to an effective display size increase by a factor of four. By contrast, a critical role for global form attributes was, for the present setup, not evident. Increasing the specification of the global form in distracters resulted in faster response latencies and lower error rates. Whether this outcome was due to a more effective rejection because of global grouping operations or effective rejection on the basis of dissimilar local inducer elements cannot be decided from the current dataset.

EXPERIMENT 3B

In Experiment 3b subjects were asked to report the goodness of figural grouping for all stimulus configurations presented in Experiment 3a (see Figure 7a) by means of a rating procedure.

Methods

The experiment was identical to Experiments 1b and 2b, except that stimulus configurations were adjusted to match Experiment 3a (see Figure 7a for examples). All eight observers had previously participated in Experiment 3a.

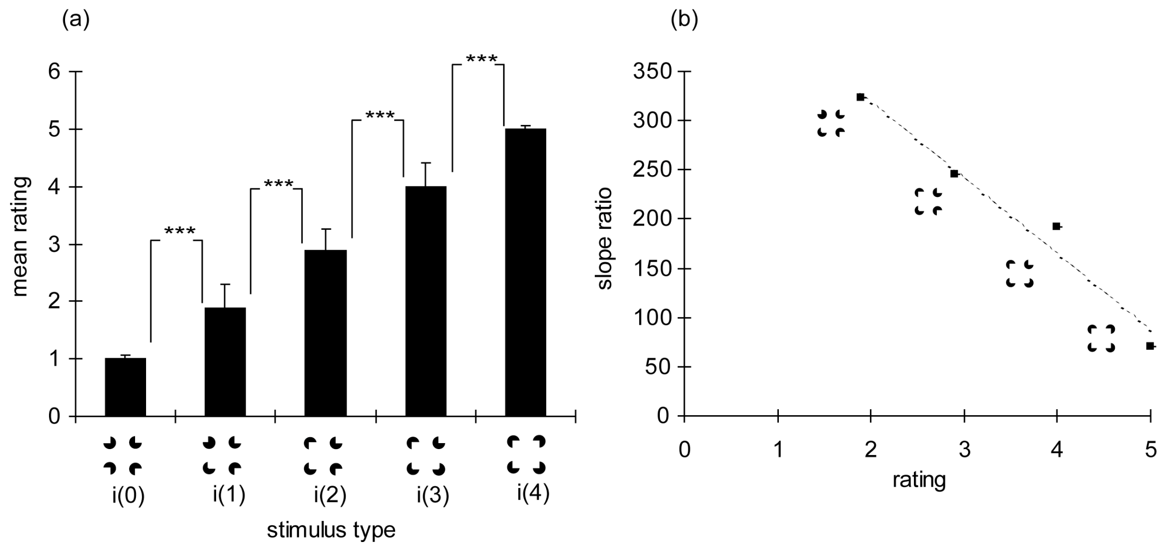

Figure 9 (a) Mean subjective figural goodness ratings (and associated SDs) as a function of stimulus type for Experiment 3b. High ratings denote a high impression of figural goodness. *** indicates the significant differences ($p < .001$) in subjective ratings between different stimulus types. (b) Mean subjective ratings (Experiment 3b) as a function of mean search rates in target absent trials (Experiment 3a) for all possible stimulus types. In addition, the illustrated best fitting linear approximation ($r^2 = .96$, $p < .05$) is shown illustrating the decrease in slopes with increases in subjective ratings.

Results & Discussion

Figure 9a presents mean rating scores (and associated standard deviations) for each stimulus configuration employed for Experiment 3a. As before, t-tests were performed to statistically compare the rating performance for each stimulus type. As can be seen in Figure 9a, statistically significant differences were obtained for each possible stimulus type. Rating scores increased linearly with every inducer that faced inwards and consequently improved completion of an illusory square.

As for Experiments 1 and 2, rating scores of Experiment 3b were contrasted with the slope of target absent search functions in Experiment 3a, to compare both performance measures. This comparison of search and rating measures again resulted in a clear effect as illustrated in Figure 9b. Contrary to previous experiments, both measures were now related by a negative linear correlation accounting for a substantial amount of variance ($r^2 = .96$, $p < .05$). Whereas search was clearly dominated by similarities between local inducers, rating performance varied in relation to the completed illusory form at a global level of representation.

Taken together, rating performance as a measure of the subjective impression of figural grouping displayed (as for previous experiments) a clear outcome that showed a strong tendency to assign high figural grouping scores in relation to the global emergent form. By contrast, search performance for Experiment 3a was dominated by similarities between local inducers. As a consequence, a comparison of both measures revealed opposite tendencies for the two approaches leading to a strong negative correlation between search based on the local representation and rating performance based on the global configuration.

EXPERIMENT 3C

Thus far, the results of Experiment 3 have demonstrated a specific role for similarities between local inducers in determining the efficiency of search performance for a (local) non-square target. However, considering the setup from search Experiment 3a (see the sample display shown in Figure 7b), a large proportion of variability might have resulted from variations in the random orientation between distracters. Besides similarity between targets and distracters, the similarity relations between distracters have been considered as a second major source in determining search efficiency (see Duncan & Humphreys, 1989). Consequently, search performance might have been impaired simply because on a given trial different distracter configurations were displayed at random orientations reducing similarity that would support successful rejection of a given (irrelevant) configuration. To control for this effect, Experiment 3c was performed similar to Experiment 3a, however, this time on a given trial observers had to detect a non-square target among distracter configurations with uniform orientations (an example display shown in Figure 7c).

Methods

The experiment was identical to the previous search Experiment 3a, except that within a given trial all distracter configurations were presented at similar orientations to minimize interference effects resulting from low similarity relations between distracters (see Figure 7c for an example display). Eight paid observers (1 male, mean age: 27.3 years) with normal or corrected-normal visual acuity participated in the experiment. All other details were identical to Experiment 3a.

Results & Discussion

RT analysis: As with Experiment 1, for Experiment 3c RTs on trials on which a response error (4.3 %) was made were removed from the RT data set prior to analysis. As for previous experiments, visual inspection of the RT distribution revealed no pronounced positive skew that would require the application of correction procedures. Figure 10 presents mean correct RTs and error rates as a function of display size separately for each of the four possible distracter types of Experiment 3c. As can be seen, the pattern of results was almost identical to Experiment 3a. Reducing the variability

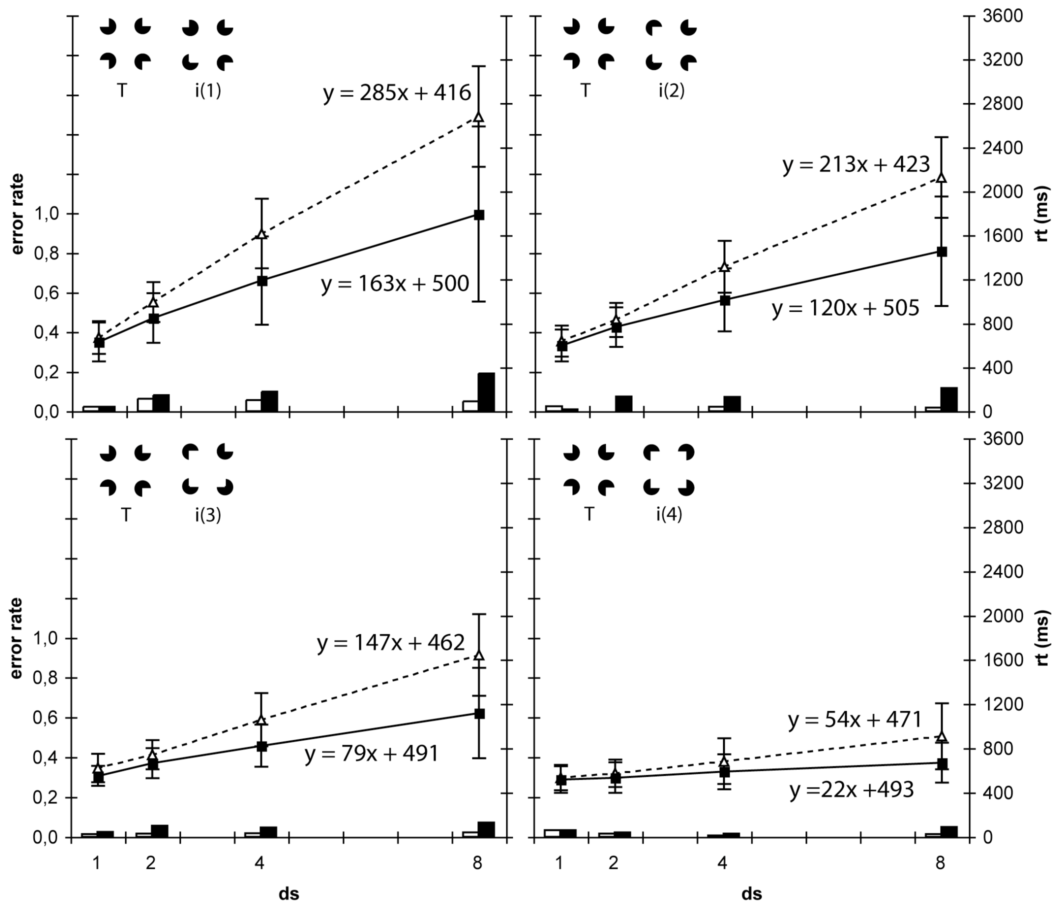

Figure 10 Mean RTs, SDs and associated error rates as a function of display size in Experiment 3c, controlling the orientation of distracters. Each graph plots a prototype target (T) and an example of a distracter grouping coding the number of inward facing inducers (i). RTs, SDs and error rates are plotted separately for target absent (dotted line, white bars) and target present trials (solid line, black bars). In addition, linear functions are given for each RT distribution depicting slopes and base rates.

between distracters only affected search efficiency to a minor extent resulting in shallower slopes. To statistically analyze the patterns of performance, RTs were again compared by means of a repeated-measures ANOVA computed on the factors *target* (present, absent), display size (*ds*: 1, 2, 4, 8 elements) and distracter type coding the number of inducers facing inwards (*in*: 1, 2, 3, 4 inwards-oriented inducers).

RT analysis revealed significant main effects [target: $F_{(1, 7)} = 48.90$, $p < .001$; ds: $F_{(3, 21)} = 139.72$, $p < .001$; in: $F_{(3, 21)} = 41.87$, $p < .001$] two-way interactions [target*ds: $F_{(3, 168)} = 65.11$, $p < .001$; target*in: $F_{(3, 168)} = 14.15$, $p < .001$; ds*in: $F_{(9, 168)} = 65.63$, $p < .001$] while the three-way interaction was also significant [target*ds*in: $F_{(9, 168)} = 3.89$, $p < .001$]. The results of Experiment 3c thus, replicated the results of Experiment 3a and indicate that search performance (expressed as a function of target x display size) varies in relation to specifications of local inducer similarities between the target and distracters. By contrast, similarity aspects between distracters cannot account for the observed RT variability.

Error Analysis: As in Experiment 1, arcsine-transformed error data were analyzed by means of identical repeated-measures ANOVA to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs. Analysis of errors showed a pattern of results similar to Experiment 3a. All main effects [target: $F_{(1, 7)} = 12.32$, $p < .01$; ds: $F_{(3, 21)} = 13.49$, $p < .001$; in: $F_{(3, 21)} = 12.30$, $p < .001$] and the two-way interactions were significant [target*ds: $F_{(3, 168)} = 10.93$, $p < .001$; target*in: $F_{(3, 168)} = 3.09$, $p < .05$; ds*in: $F_{(9, 168)} = 3.32$, $p < .001$]. However, unlike Experiment 3a, the three-way interaction was non-significant showing that a reduction in distracter-distracter similarity had a facilitatory effect on the amount of errors that were made. No other significant effects were obtained.

In sum, Experiment 3c replicated the outcome of Experiment 3a in showing that the major source of interference with search is the similarity between local inducers defining targets and distracters. Introducing distracter configurations with uniform rotation certainly improved performance, however, the resulting effects yielded slope decreases of maximally 30 % but did not affect the overall pattern of results. Consequently, statistical effects were almost identical in both experiments and thus, the results from both Experiments 3a and 3c indicate that search for a local non-square configuration is determined by the local inducer similarity aspects between targets and distracters. By contrast, if a target comprises a global form (as for Experiments 1 and 2), emergent properties of the distracter will mostly affect performance. Given the present case where the target does not exhibit (global) emergent properties, local aspects dominate search and consequently are a major source of interference.

EXPERIMENT 4

Experiment 3 clarified the role of similarity at global and local levels of objects interfering in search. Depending on critical aspects defining the target, both levels may lead to interference. Considering Experiment 1, the emergence of a global form representation was found to be a major source of interference in search for an illusory square. This global form effect reported for Experiment 1 was reinvestigated in further detail in the current Experiment 4 with the aim to specify underlying processes of interference. One possibility to explain the observed decline in search could be, that global form interference is caused by a memory-like system coding multiple objects (i.e. targets and distracters) with a capacity limitation of resources. However, contrary to this conception a second alternative might be drawn from 'early', parallel models that code salient attributes of objects in the visual scene without capacity limitation. In this view, interference would not result from limited resources, but from the representation of too many salient targets in the visual field.

To investigate both alternatives of explanation, Experiment 4 was designed to determine the progression of interference in a design that continuously increased the number of potential targets. As in the previous experiments, participants were asked to search for a target Kanizsa square. Contrary to previous experiments, displays always consisted of 8 candidate groupings. Distracters were either standard non-square (‘placeholder’) distracters or global form and global border configurations as in Experiment 1. Using this approach, search performance was investigated under a gradual increase of interfering global representations in distracters.

Methods

Experiment 4 was identical to Experiment 1 with the following exceptions: Participants were always presented with an eight-element display and were asked to report the presence or absence of a Kanizsa target square. Distracter items could either be defined as a standard configuration (with inducing elements rotated outwards by 180 degrees to suppress illusory figure formation – see D(0) distracters in Figure 1) or alternatively one of four possible interference configurations (i.e. global border and form distracters labeled D(1) and D(2), see Figure 1). Consequently, display size was now coded as ‘interference display size’ coding 0-7 candidate groupings potentially interfering with search. Eight paid participants (5 male, mean age: 25.5 years) with normal or corrected-normal vision performed the experiment.

In total, the experiment consisted of four sessions that always presented observers with one type of interference distracter in random order. For each session, 8 blocks were presented containing 80 trials each and resulting in 40 trials per experimental condition.

Blocks were administered in random order. All other details were identical to the methods described for Experiment 1.

Results & Discussion

RT analysis: As with Experiment 1, for Experiment 4 RTs on trials on which a response error (2.7 %) was made were removed from the RT data set prior to analysis. Visual inspection of the RT distribution revealed no pronounced positive skew, consequently no correction procedures were applied. Figure 11 presents mean correct RTs and the percentage of errors as a function of the interference display size for each of the four possible interference distracters. Interestingly, the graphs for each interference distracter reflect a continuous increase without depicting any critical steps. To statistically analyze the effects, RTs and error rates were subject to a repeated-measures ANOVA computed on the factors *target* (present, absent), interference display size (*ids*: 0, 1, 2, 3, 4, 5, 6, 7 elements) and interference distracter type (*idt*: 1B, 2B, 1F, 2F configurations coding the number of supporting contours and global Form/Border types, examples shown in Figure 11).

RT analysis revealed the main effects [target: $F_{(1, 7)} = 21.37$, $p < .01$; ids: $F_{(7, 49)} = 57.85$, $p < .001$; idt: $F_{(3, 21)} = 15.14$, $p < .001$] and two-way interactions [target*ids: $F_{(7, 364)} = 10.77$, $p < .001$; target*idt: $F_{(3, 364)} = 77.27$, $p < .001$; ids*idt: $F_{(21, 364)} = 18.02$, $p < .001$] to be significant. The three-way interaction was also significant [target*ids*idt: $F_{(21, 364)} = 4.41$, $p < .001$] and was due to an increase in slopes for each of the target*ids functions that was specific to distracters containing global form and global border information. Thus, an increase in the number of distracters leading to global interference resulted in increases reflecting previous performance deteriorations using similar stimulus types. Thus, the present results reflect the outcome from Experiment 1 in showing that interference results from global form but not from borders.

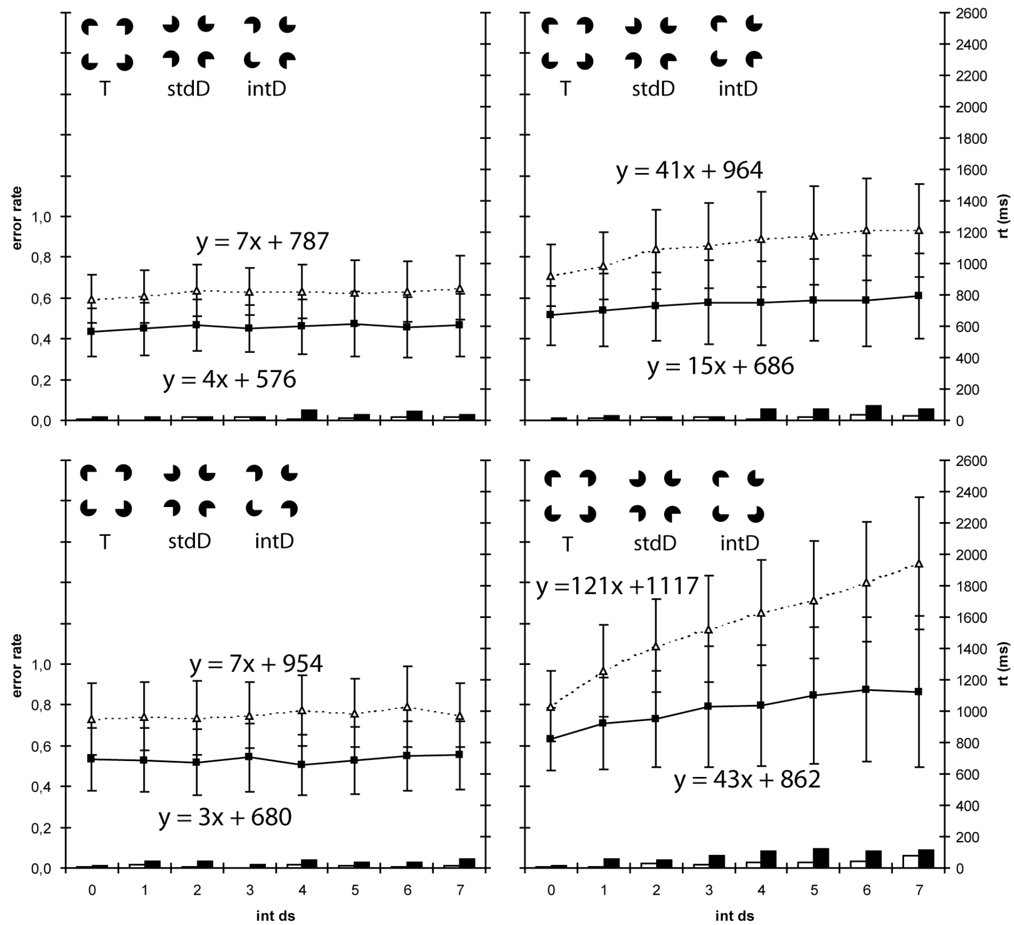

Figure 11 Mean RTs, SDs and associated error rates as a function of the interference display size (int ds) in Experiment 4. Each graph plots a prototype target (T) and examples of the standard and interference distracters (stdD and intD, respectively) presenting global border (left column) and global form distracters (right column). RTs, SDs and error rates are plotted separately for target absent (dotted line, white bars) and target present trials (solid line, black bars). In addition, linear functions are given for each RT distribution depicting slopes and base rates.

Error Analysis: As in Experiment 1, arcsine-transformed error data were analyzed by means of identical repeated-measures ANOVA to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs. Analysis of errors revealed a pattern of results comparable to the RT analysis. All main effects [target: $F_{(1, 7)} = 28.01$, $p < .01$; ids: $F_{(7, 49)} = 8.61$, $p < .001$; idt: $F_{(3, 21)} = 8.48$, $p < .001$] and two-way interactions were significant [target*ids: $F_{(7, 364)} = 3.52$, $p < .01$; target*idt: $F_{(3, 364)} = 4.21$, $p < .01$; sds*idt: $F_{(21, 364)} = 1.89$, $p < .05$] whereas the three-way interaction was non significant showing that error rates remained at a constant level independent from variations of interference distracters. No other significant effects were obtained.

To summarize, Experiment 4 replicated the major outcome from Experiment 1 in showing that the global form is of major importance to induce similarity-based interference between illusory figure target and distracter configurations. As can be seen in Figure 11, global border configurations had virtually no effect and did not lead to an increase in slopes. By contrast, global form distracters influenced performance markedly and resulted in prolonged RTs as a function of the interference display size. A stepwise increase of interfering global form distracters from zero to seven configurations led to a monotonous reduction of response latencies without depicting any critical steps in the progression of interference. Consequently, no evidence in support of a memory-based, capacity-limited model of search was found. Rather, the empirical evidence points towards a parallel model coding information without capacity limitations across the visual scene.

General Discussion

The current set of experiments was conducted to reconsider equivocal results from previous studies investigating the role of completion processes in search for Kanizsa figures (Grabowecky & Treisman, 1989; Davis & Driver, 1994; Gurnsey et al., 1996). The paradigm employed systematic variations of target-distracter similarity to identify specific critical processes for successful detection performance. In considering the illusory figure as a multi-level stimulus configuration, global and local object attributes were varied to decide upon their relative impact on search.

Four experiments reveal a distinct pattern of results with very specific indications of the influence of global and local object attributes for the processing of illusory figures. Experiment 1 investigated the role of global border and form information for detection of an illusory square. Results suggest that interference between targets and distracters results from specifications of the global emergent form whereas global border information defining shape boundaries did not lead to interference. In extension to this finding of a global form effect, Experiment 2 decomposed critical aspects of form attributes by attempting to segregate surface characteristics from the surrounding contours that define shape boundaries. The results demonstrated that the effect of global form cannot be understood as a function of the defining contour since variations of contours independent from the surface (in the global outline condition) did not exhibit an influence upon performance. To summarize, both experiments have demonstrated a specific role for the global form in detecting a target Kanizsa figure. Following this investigation of global factors, Experiment 3 investigated the effects of local object attributes upon the efficiency of search. Results revealed that the emergence of form is not a defining attribute of search performance per se. When observers were asked to detect a non-square target lacking a global level of representation, search efficiency was determined by target-distracter similarity of local aspects related to inducer elements but was not influenced by global stimulus aspects. Finally, Experiment 4 returned to the global form effect demonstrated in Experiment 1 and investigated how interference progresses with an increase in the number of conflicting distracters. The results demonstrated a monotonic increase of interference that is consistent with parallel mechanisms coding form attributes across the visual field.

Complementary to these outcomes illustrated for speeded responses in visual search tasks, Experiments 1-3 also tested the subjective impression of figural grouping for all stimulus configurations by means of a rating procedure. For all three rating experiments (1b, 2b, 3b), the goodness judgment of a stimulus configuration varied with the specification of the emergent form. Consequently, both RT measures and unspeeded phenomenal ratings showed similar patterns when the global form level of representation was emphasized (Experiments 1 and 2). By contrast, a negative relationship was observed between search and rating experiments when search depended on local attributes but rating maintained emphasis on the global level (Experiment 3). Taken together, judgments of figural goodness by means of a rating procedure showed a clear relation to the global emergent form.

One consistent outcome from all search experiments that were described is the demonstration of a competitive target-distracter interaction in search performance. The results show that groupings comprising a multilevel organization interact during search at that level which critically defines the target. Depending on the level of organization of the target, similarity can either interact at global-form or local-inducer levels of representation. This finding extends similarity theories that hypothesize that grouping mechanisms form preattentive perceptual units that become the substrates for search and other higher-order processing (Duncan, 1984; Duncan & Humphreys, 1989). In accordance with this claim, the efficiency of search in the present experiments can be attributed to processing stages after the visual field has been parsed into global representations. Increasing the figural relevance at the global form level results in higher similarity-dependant competition between candidate target configurations and slows down search. By contrast, effects of similarity at the level of the inducers was observed when the target representation lacked a global level of coding. Now target distracter similarity depended upon local levels of the inducer with search being based upon single elements of a candidate configuration. Consequently, similarity does not need to 'spatially group' to have an effect on search performance.

Experiments 1, 2 and 4 exhibited a critical role for the global level of organization, showing that only global form (i.e. the surface) had an influence on the behavioral response. For the search experiments, the influence of the global form contrasted with no influence of global border specifications. In addition, rating performance for all experiments showed that the basis of the subjective impression could be related to surface characteristics. In this respect, no direct link can be drawn between the outcome of visual search experiments (Davis & Driver, 1994) and physiological studies of the low-level neuronal responses to illusory contours (von der Heydt et al, 1984; Peterhans & von der Heydt, 1991; Lee & Nguyen, 2001), because search for a Kanizsa square depends solely on the global form (Experiment 2), contrasting with physiological studies reporting neuronal responses to contours. From computational models, it might be assumed that the processes of contour completion and the filling-in of emergent form are completed by separate systems (Grossberg & Mingolla, 1985; 1987). The emphasis on form information presented for the present experiments in turn suggests that filling-in of surface information is achieved before a precise boundary has been computed (i.e. Stanley & Rubin, 2003) pointing towards the importance of extracting salient regions in rapid analysis of a visual scene. Indeed, psychophysical evidence suggests that global surface properties of objects can capture attentional resources (Rauschenberger & Yantis, 2001). Also, search performance seems to rely in many cases on a completed representation of object fragments (He & Nakayama, 1992; Rensink & Enns, 1998; Davis & Driver, 1998). From a physiological perspective mechanisms capable of determining salient regions might be represented in a recurrent network operating at various levels of the visual hierarchy (Lee & Nguyen, 2001; Roelfsma, Lamme, Spekreijse & Bosch, 2002) in the process of integrating surface information and extracting their boundaries.

CHAPTER III

Electrophysiological correlates of similarity-based interference during detection of visual forms

Abstract

Illusory figure completion demonstrates the ability of the visual system to integrate information across gaps. Mechanisms that underlie figural emergence support the interpolation of contours and the filling-in of form information (Grossberg & Mingolla, 1985). While both processes secure figure formation, visual search for an illusory target configuration has shown to be susceptible to interfering form information while neglecting information about contours (see Chapter II). Here, the physiological basis of form interference was investigated by recording event-related potentials elicited from contour- and surface-based distracter interactions with detection of a target Kanizsa figure. The results replicated the previous form interference and demonstrate that selection of the target and successful suppression of the irrelevant distracter is reflected by amplitude differences in the N2pc component (240-340 ms). In conclusion, the observed component variations reflect processes of target selection on the basis of integrated form information resulting from figural completion processes.

Introduction

Illusory figures demonstrate the ability of the visual system to integrate missing information across gaps. Natural scenes typically contain multiple overlapping objects while offering only sub-optimal viewing conditions. Within such environments, one plausible biological function for figural completion processes refers to the registration of objects that would otherwise be camouflaged. This 'anti-camouflage' mechanism (Ramachandran, 1987) provides the phenomenal emergence of figural information. For example, in Figure 1a (T), a square is induced and perceived as occluding the neighboring circular inducer elements. Subjectively, the emergence of shape information exhibits a bright central region that is surrounded by sharp boundaries without a corresponding physical correlate (Kanizsa, 1955).

Related approaches that intended to isolate the neural mechanisms of figural completion processes have identified various sources along the ventral stream. Results from physiological recordings indicate that cells in V1 and V2 code illusory contours comparable to real contours (von der Heydt, Peterhans & Baumgartner, 1984; Peterhans & von der Heydt, 1991; Lee & Nguyen, 2001). While activations specific to illusory contours have also been found in striate and extrastriate visual areas in humans (Ffytche & Zeki, 1996; Murray, Wylie, Higgins, Javitt, Schroeder & Foxe, 2002; Ritzl, Marshall, Weiss, Zafiris, Shah, Zilles & Fink, 2003), a major source of processing has also been located in the lateral occipital complex (LOC) and fusiform gyrus (Hirsch, de la Paz, Relkin, Victor, Kim, Borden, Rubin & Shapley, 1995; Stanley & Rubin, 2003; Halgren, Mendola, Chong & Dale, 2003). In agreement with extrastriate sources of illusory figure perception, human EEG correlates typically have been reported in the N1 component peaking at ~80-150 ms after stimulus onset at occipito-parietal sources (Murray et al. 2002; Pegna, Khateb, Murray, Landis & Michel, 2002; Murray, Foxe, Javitt & Foxe, 2004). Consequently, activity elicited by illusory figures seems to be represented in various regions specialized in object processing. Early V1 and V2 activations within this pattern could reflect the interpolation of contours, while LOC and fusiform gyrus activity may be interpreted in terms of a filling-in of surface information (Stanley & Rubin, 2003; see also Grossberg & Mingolla, 1985 for a related computational model).

To relate outcomes from physiological studies to behavioral measures, psychophysical investigations attempted to uncover the underlying processes of object completions by employing visual search techniques. Experiments typically require observers to search for a target among distracter items while reaction time (RT) measurements or the processing time per item allow distinguishing efficient from inefficient search (Treisman & Gelade, 1980). Following this rationale, search for a Kanizsa square could be performed independent from the number of distracter configurations presented concurrently with the target suggesting efficient (i.e. parallel) performance (Davis & Driver, 1994; see Figure 1a, I; for example stimuli) in correspondence to physiological outcomes (von der Heydt et al., 1984). However, closer examinations of the effect have questioned the specific impact of the illusory figures on search performance (Gurnsey, Poirier & Gascon, 1996). Consequently, follow-up experiments intended to identify more specifically how shape attributes are coded for search. Systematic variations were employed to determine the impact of surfaces and contours in distracters interfering with efficient target Kanizsa figure detection (see Chapter II). The results depicted no interference for distracters that contained contour completions (see Figure 1a, II; for example target and 'border' distracter configurations). By contrast, a robust search interference effect was observed for distracters containing surface information (see Figure 1a, III; for example target and 'form' distracter configurations). Thus, a major contribution of the illusory figures upon search can be attributed to processes supporting the filling-in of surface information while interfering with successful target detection (see Duncan & Humphreys, 1989). As a result, visual search performance does not support a link to illusory contour completions as attributed to area V2 (von der Heydt et al., 1984) but might relate to surface filling-in mechanisms within the LOC and the fusiform gyrus (Hirsch et al., 1995; Stanley & Rubin, 2003).

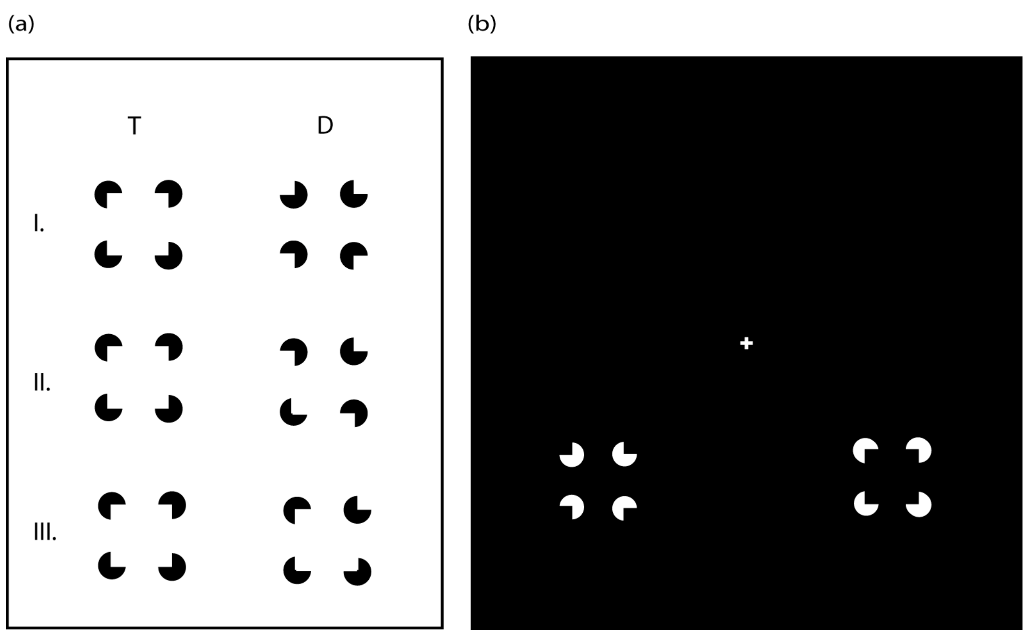

Figure 1 (a) Possible pairs of target (T) and distracter (D) configurations in the experiment. The target configuration was always defined as a Kanizsa square. By contrast, distracters were arranged such that three possible configurations resulted which were referred to as standard (I.), border (II.) and form (III.) types. (b) Example of a target present search display showing the two possible stimulus locations in the experiment (see Methods).

In the present study, shape information in distracters and their interfering effect upon target detection was analyzed by investigating variations in the event related potential (ERP) extracted from the human electroencephalogram (EEG). As described above, visual search has shown specific interference effects of form information on the detection of a target Kanizsa figure. The current experiment aimed to specify the corresponding physiological correlates of form distracter interference. Previous work has typically evaluated how contour and surface information correlates with a specific neural pattern (i.e. Murray et al., 2002). Here, interference from surface and contour information was studied by presenting observers with search displays that contained two candidate target configurations (see Figure 1b for an example display), thus, allowing to determine the impact of a specific distracter attribute (i.e. its border or form) upon detection of the target configuration. As will be shown, variations of search performance resulting from distracter interference revealed specific variations within the N2pc component, which is interpreted as reflecting the allocation of attentional resources upon a selected target (Luck & Hillyard, 1994a; Eimer, 1996).

EXPERIMENT 5

Methods

Participants: Ten right-handed observers (4 male, mean age = 26.2 years) with normal visual acuity participated in the experiment for payment of 8 Euro per hour.

Apparatus and Stimuli: Stimulus generation, event timing and trigger signals were controlled by an IBM-PC compatible computer. Stimuli were presented in dark white (1.83 cd m^{-2}) against a black (0.02 cd m^{-2}) background at the bottom left and right quadrant of a 19-inch computer monitor (see Rubin, Nakayama & Shapley, 1996). Each stimulus configuration was diagonally shifted by 8.75° from a centrally presented fixation cross (see Figure 1b for an example). At a viewing distance of 110 cm, each candidate grouping (composed of four inducing elements with a diameter of 1°) subtended a viewing angle of 2.9 x 2.9°. As depicted in Figure 1a, the target (T) was always defined as a Kanizsa square, whereas distracter (D) groupings were obtained by rotating inducer elements so that these could be categorized as standard (Figure 1a, I), border (Figure 1a, II) or form (Figure 1a, III) types. Inducers for the standard distracter were rotated with the aperture of each inducer facing outwards such that no illusory figure was induced. By contrast, inducers that supported border and form distracters were arranged such that they promoted an emergent surface or contour induced from two illusory continuations between neighboring elements.

Procedure: Each trial started with the presentation of a fixation cross for a randomized period of 500-600 ms at the center of the screen. After this period, two candidate target configurations at random orientations were added at bottom left and right quadrants. Following stimulus onset, observers responded with a speeded target absent/present response via mouse keys while fixating the center of the screen. Displays remained on-screen until a response was given. In case of an erroneous response or a time-out (after 2500 ms), feedback was given by a computer-generated tone and an alerting message presented for 500 ms at the center of the screen. Each trial was followed by an ISI of 1000 ms.

The experiment started with 50 practice trials. Subsequently, 1200 experimental trials were presented in 2 sessions with 6 blocks containing 100 trials each, resulting in

50 trials per experimental condition. For each session response mappings were pseudo-randomly switched for each participant between left and right hand to control for compatibility effect between stimulus position and response hand (Fitts & Seeger, 1953). Blocks within each session were administered in pseudo-random order on a subject-by-subject basis.

EEG Recording: The EEG was recorded continuously by a BrainAmps system (Brain Products) from 64 Ag-AgCl electrodes according to the extended international 10-20 system (American Electroencephalographic Society, 1991) with a sampling rate of 500 Hz. The electrodes were mounted in an elastic cap (FM Services). Vertical and horizontal eye-movements were monitored with electrodes placed at the outer canthi of the eyes and the superior and inferior orbits. Electrophysiological signals were amplified and on-line filtered using a 0.1-100 Hz bandpass. All electrodes were referenced to Cz. Signals were then 30-Hz lowpass filtered and averaged offline over a 1000-ms epoch including a 200-ms pre-stimulus baseline. Trials containing incorrect responses, EOG-artefacts, excessive peak-to-peak deflections (i.e. $>100\ \mu V$ or $<-100\ \mu V$) or bursts of electromyographic activity were excluded from averaging.

Analyses: The current experiment was performed with the aim of identifying a physiological correlate of similarity-based interference between attributes of the distracter configuration and attributes of the target figure. Consequently, only target present trials were included in the subsequent analysis of behavioral performance and ERPs.

For the behavioral analysis, RTs on trials on which a response error (6.8 %) was made were removed from the RT data set prior to analysis. RTs and arcsine-transformed error rates were each analyzed by means of a repeated-measures Analysis of Variance (ANOVA) computed on the factors distracter type (*dt*: standard, border, form), target position (*tp*: left, right) and response mapping (*rm*: left, right response button for target present).

Analysis of the ERPs began by identifying latency windows of the standard P1, N1 and N2 components in the grand average waveforms. Components were determined in the following post-stimulus time windows: 60-120 ms (P1), 120-210 ms (N1), and 210-340 ms (N2). Figure 3 (bottom left) illustrates the corresponding ranges. Within these predefined windows, peak amplitudes and latencies for P1, N1 and N2 components were extracted. In order to statistically compare amplitudes and latencies for component peaks, repeated-measures ANOVA was employed for a selection of posterior electrode pairs (O1/O2; PO7/PO8; P5/P6). ANOVAs were computed on the factors *electrode* (electrode 1, electrode 2), target position (*tp*: left, right) and distracter type (*dt*: standard, border, form).

In a second step of the EEG analysis, the N2pc component was extracted to evaluate condition-specific variations in further detail by means of lateralized potentials. Difference waves were computed by subtracting ERPs at electrode positions ipsilateral to the target location from ERPs at electrode positions contralateral to the target. Left and right target locations were collapsed for this procedure. As for the ERP analysis, a set of posterior electrode pairs (O1/O2; PO7/PO8; P5/P6) was statistically evaluated. Analysis was performed on peak amplitudes and latencies that were extracted in the 240-340 ms range. Repeated-measures ANOVAs were computed for each lateralized component (occipital, occipito-parietal and parietal) on the factor distracter type (*dt*: standard, border, form).

Results

Behavioral analysis: Visual inspection of the RT distribution revealed no pronounced positive skew, which would require the application of correction procedures. Figure 2 presents mean correct RTs and the percentage of errors as a function of the distracter type for target present trials.

The RT ANOVA revealed main effects of distracter type and response mapping [dt: $F_{(2, 18)}= 4.33$, $p < .03$; rm: $F_{(1, 9)}= 8.98$, $p < .02$]. Response latencies increased from standard- through border- to form distracters that were presented together with the target. In addition, responses to the target with the right hand were faster than responses to the target with the left hand. No other significant effects were obtained.

ERP analysis: Figure 3 presents grand average ERP waveforms elicited at left (P5, PO7, O1) and right (P6, PO8, O2) posterior electrodes. The examples shown provide the response to a target Kanizsa square presented in the lower left quadrant of the visual field. Peak latency and amplitude differences for both P1 and N1 components revealed no significant effects. By contrast, the ANOVA on the N2 component resulted in a significant effect of peak amplitudes. For occipital electrodes, the main effect of target position [tp: $F_{(1, 9)}= 8.69$, $p < .02$] and the interactions of electrode with target position and distracter type [electrode*tp: $F_{(1, 9)}= 8.53$, $p < .02$; electrode*dt: $F_{(2, 18)}= 4.15$, $p < .04$] reached significance. The main effect of position revealed a more negatively inclined deflection for right as compared to left hemifield target presentations. In addition, the

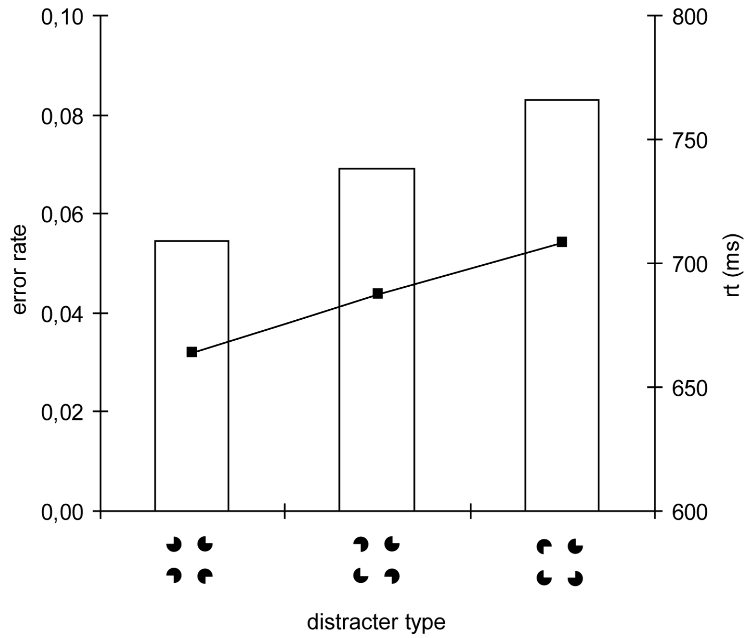

Figure 2 Mean target present RTs and associated error rates as a function of distracter type in Experiment 5. The white bars and the black solid line correspond to the error rates and response latencies, respectively.

interaction of target position with electrode demonstrated a more negative amplitude deflection for left visual field targets at right hemisphere electrodes and vice versa. Finally, the interaction of electrode and distracter type showed that border and form distracters were more negative than the standard distracter at electrode O1. By contrast, electrode O2 showed comparable amplitudes for border and standard distracters and more negative amplitude only for the form distracter type

Consistent with the significant effect at occipital sites, an interaction between electrode and target position was also manifest at occipito-parietal [electrode*tp: $F_{(1, 9)}= 7.08$, $p < .03$] and parietal electrodes [electrode*tp: $F_{(1, 9)}= 8.65$, $p < .02$] in the N2 range. As for occipital electrodes, the interaction showed larger negative deflections for contralateral target presentations. Maximal variations of this effect were observed for occipito-parietal electrodes. No other significant ERP effects were obtained for this selection of electrodes.

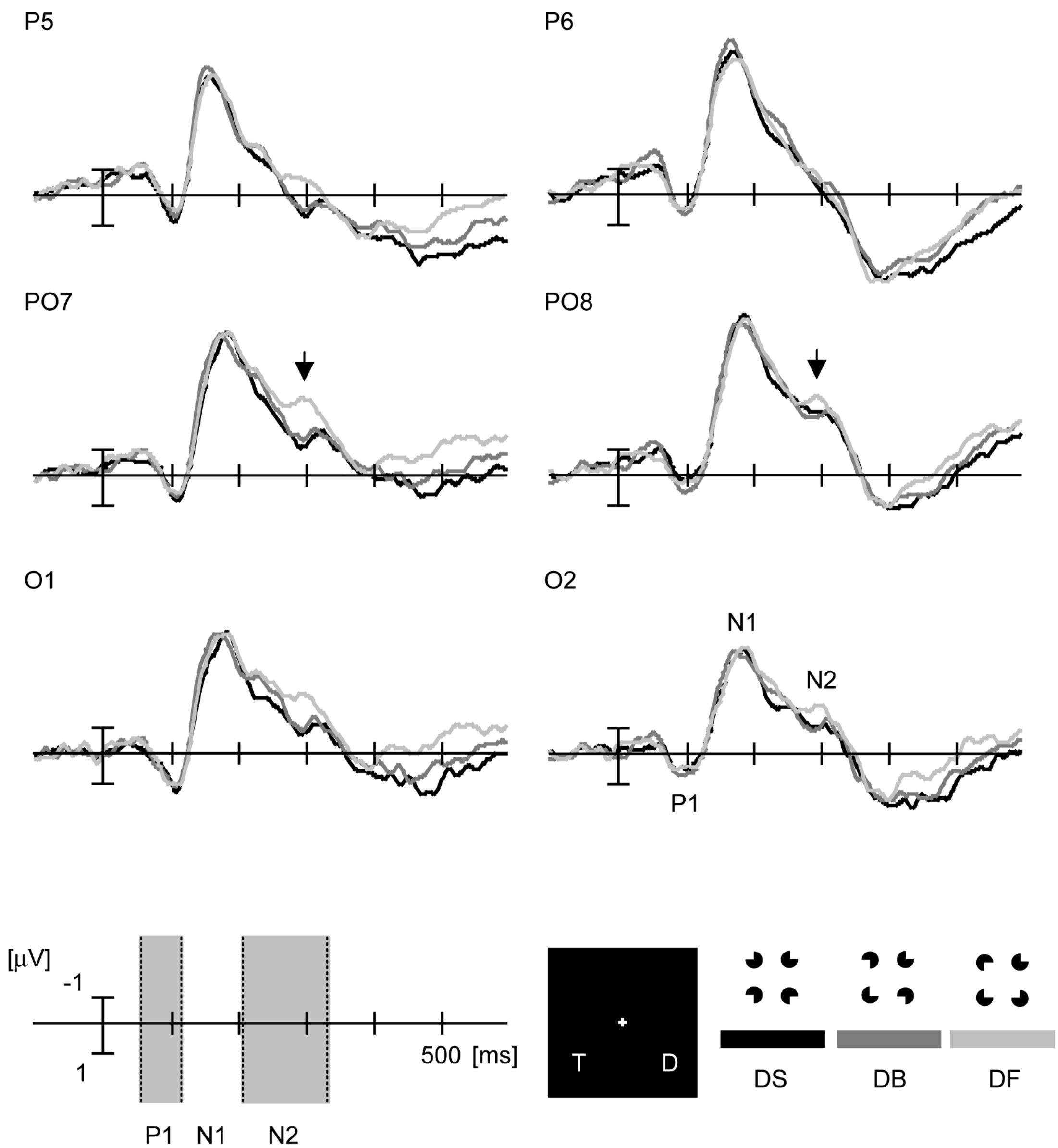

Figure 3 Grand average ERP waveforms elicited at left (P5, PO7, O1) and right (P6, PO8, O2) posterior electrodes in response to a Kanizsa square target (T) and a distracter (D) presented in the lower left and right quadrants of the visual field. Black, dark-grey and light-grey lines correspond to standard (DS), border (DB) and form (DF) distracter types presented with the target in the lower left quadrant. Black arrows indicate the maximum of the N2pc component. Graphs are plotted with negative voltages upward and time zero representing stimulus onsets.

Analysis of lateralized components: Figure 4 presents grand average difference waves (contra- minus ipsilateral), separately for each distracter type in standard, border and form conditions. Statistical analysis of the N2pc revealed a significant main effect of distracter type for the analysis of amplitude differences at occipital [$F_{(2, 18)} = 4.86$, $p < .03$], occipito-parietal [$F_{(2, 18)} = 5.88$, $p < .02$] and parietal [$F_{(2, 18)} = 5.32$, $p < .02$] electrodes. The results for all three electrode sites showed that differences between lateralized components for form distracters were less negative than border or standard distracters.

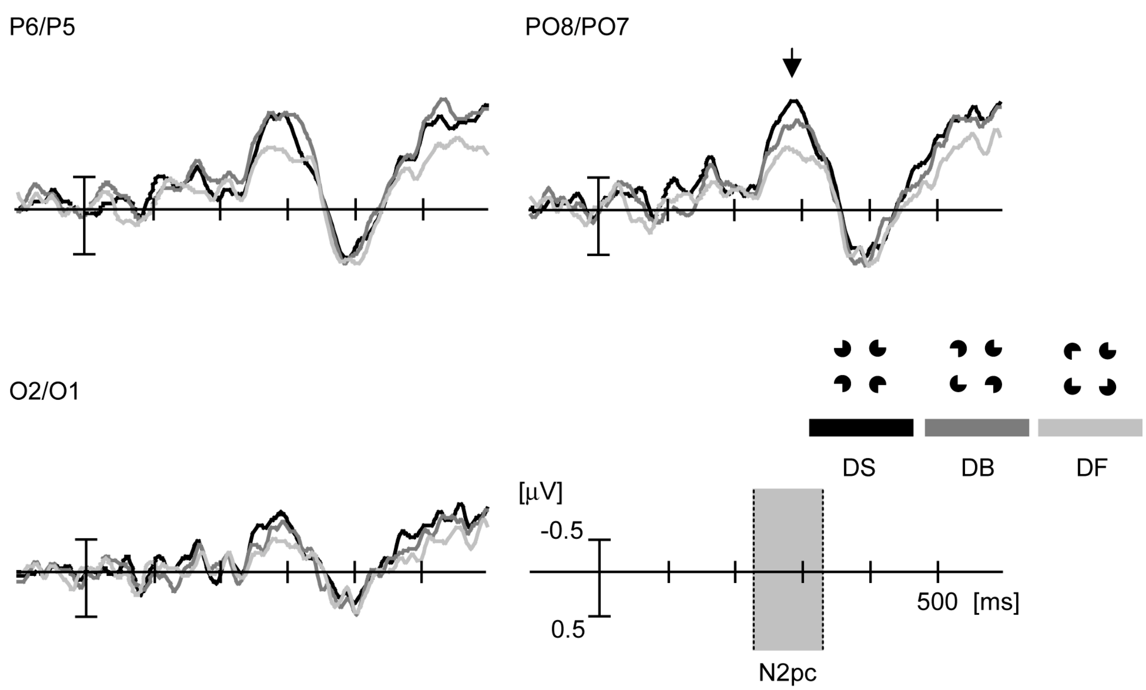

Figure 4 Lateralized grand average difference waves at parietal (P6/P5), occipito-parietal (PO8/PO7) and occipital (O2/O1) electrode positions. Difference waves were constructed by subtracting ERPs at electrode positions contralateral to the target location from ERPs at electrode positions ipsilateral to the target. Black, dark-grey and light-grey lines correspond to standard (DS), border (DB) and form (DF) distracter types presented with the target configuration. The black arrow indicates maximum variability of the N2pc component at occipito-parietal electrode positions. Graphs are plotted with negative voltages upward and time zero representing stimulus onsets.

Discussion

Behavioral analysis revealed that efficiency in visual search for an illusory target figure depends critically upon the specification of distracter attributes. Response latencies and error rates increased from standard- through border- to form distracters suggesting that figural information interferes with successful target detection. Presenting illusory contours for the border distracter type concurrently with a target led to increases in response latencies and error percentages. Furthermore, the presentation of surface information for the form distracter type led to even larger increases in performance measures. In sum, behavioral outcomes demonstrate that emergent figural information is coded for search resulting in larger interference with successful target detection for more similar figural information in distracters.

Analyses of the ERP data for posterior electrodes revealed no effects for early P1 and N1 components. Only within the N2 time window significant effects were obtained demonstrating more negative deflections contralateral to the stimulated target quadrant. In addition, at left occipital electrodes the significant interaction of electrode and distracter type showed that figural information in distracters was processed differently from the standard distracter. In a subsequent step, a narrower time window was chosen for further analysis that computed lateralized difference waves and demonstrated specific effects of distracter type. Difference waves exhibited smaller amplitude deflections for form distracters as compared to standard or border distracter types (see Figure 4, black arrow). This finding is consistent with the behavioral pattern of results and shows an electrophysiological correspondence of the form distracter interference with the target Kanizsa figure. By contrast, difference waves corresponding to standard or border distracter types showed larger amplitude deflections. This pattern of results corresponds to the observed variations for the behavioral performance and supports an account of similarity-based target-distracter interference. According to this account, form distracters share most attributes with the target. As a result, the negative deflection contralateral to the form distracter exhibits the highest negativity (see Figure 3, electrode PO7 - black arrow) comparable to activations in response to a target (see Figure 3, electrode PO8 - black arrow) while the respective difference curve reaches only a relatively small deflection (see Figure 4, electrodes PO8/PO7 - black arrow).

In sum, both behavioral and EEG measures exhibit a pattern of results consistent with an account of similarity-based interference in processing the illusory figure. Presenting emergent form information in distracters interferes most with detection of the target while it exhibits most similar attributes. In correspondence to behavioral performance, the N2pc component depicts the largest negativity when coding form information in distracters supporting a role in coding (emergent) figural information for target selection.

General Discussion

The experiment presented here intended to isolate an electrophysiological correlate of similarity-based object interactions in a task involving the detection of a target Kanizsa figure. While behavioral results replicated previous outcomes demonstrating that interference results primarily from emergent form information (see Chapter II), analysis of ERPs in the current experiment suggests that this effect can be attributed specifically to the time window ranging from 240 to 340 ms post stimulus at posterior electrode positions. Attentional shifts to the target location were reflected in ERP measures by a substantial N2pc activation. However, the reported behavioral target-distracter interference effect was also reflected in the N2pc component window. Activations to the target elicited high N2pc components for all conditions. By contrast, N2pc activations elicited by distracters depended on whether the configuration contained a salient attribute that was similar to the target. Thus, salient information as signalled by the displayed figural configurations guides target selection processes. Standard and border distracter types elicited relatively small negative deflections mirroring the efficient behavioral performance in visual search. By contrast, the form distracter type yielded a large negative going deflection that was comparable to the target-related activation pattern. Consequently, the results presented here mirror behavioral performance and reflect the registration of integrated object attributes that are coded for successful search performance.

In comparison to previous electrophysiological studies that reported activations in response to illusory figures within the N1 component (Murray et al., 2002; 2004; Pegna et al., 2002), the current effects occur rather late. However, previous experiments did not require the selection of a target among distracters but presented the illusory figure in isolation. Thus, the N2pc activation reported here does not necessarily contradict previous work but specifies processes related to the allocation of attention to a specified target location. By contrast, effects within the N1 component have been attributed to the specification of processes related to stimulus encoding itself (i.e. Murray et al., 2002).

The finding of an N2pc-specific effect reflecting the efficiency of allocating attention to the target location is also in close agreement with a variety of experimental reports. Luck and Hillyard (1994a) have shown that an N2pc component was elicited by 'pop-out' targets defined within a single feature dimension while being absent in response to all distracters of the stimulus array. Consequently, the N2pc activity may indicate a shift of attention to a relevant target location. While a variety of stimulus dimensions (i.e. form, color) produce an N2pc component, the effect can also be observed when the target is presented with just one distracting stimulus (Eimer, 1996). In addition, the N2pc component has been described not only for targets, but also for non-targets that either comprise a salient pop-out feature (Luck & Hillyard, 1994a) or require careful examination to be distinguished from the target (Luck & Hillyard, 1994b). Furthermore, magnetic field recordings have shown that the N2pc mirrors detection of task-relevant features before spatial attention is allocated (Hopf, Boelmans, Schoenfeld, Luck & Heinze, 2004). Source localization of N2pc-related activity revealed an early parietal component and a later occipital activation pattern (Hopf, Luck, Girelli, Hagner, Mangun, Scheich & Heinze, 2000).

A comparison of previous work with the current outcomes shows close links and correspondences. In agreement with Luck and Hillyard (1994a) and Eimer (1996), the N2pc elicited by a target Kanizsa figure is larger than the corresponding activation elicited by distracter configurations. In addition, similarity between target and distracter configurations was reflected in the lateralized amplitude differences within occipito-parietal cortex comparable to the pattern obtained for other reported variations of target discriminability (Luck & Hillyard, 1994b). While large form-based interference was reflected by small amplitude differences, the contrary could be observed for stimuli that elicited efficient search while inducing relatively small target-distracter interferences (i.e.

standard and border distracter types). The maximum variability of this pattern at occipito-parietal electrodes closely resembles other reports investigating the emergence of surface characteristics in area LOC (Murray et al. 2002; Stanley & Rubin, 2003). Consequently, this may be taken to indicate that search performance reflects analysis of candidate target stimuli based upon the completed representation of illusory shape information. Latency ranges (240-340 ms post stimulus onset) and the occipito-parietal maximum, in addition, roughly correspond to the latter subcomponent extracted within the N2pc time window (Hopf et al., 2000).

In conclusion, the observed N2pc modulation may indicate a shift of attention to a relevant target location on the basis of salient region computations (Stanley & Rubin, 2003). Within this framework, surface characteristics but not the contour interpolations contribute to salient region estimations that are extracted for a crude initial analysis of the visual scene to guide efficient selection.

CHAPTER IV

Closure of salient regions determines search for a collinear target configuration

Abstract

Grouping operations offer an effective mechanism to structure complex visual input. Besides various principles mediating element integration, closure may be regarded as a main cue for shape extraction. Here, three experiments investigated the relative impact of grouping by means of closure in search for a collinear target configuration. Systematic variations of distracter configurations composed from collinear line segments were explored to investigate how form information interferes with target detection. Results showed no search interference for distracter configurations that exhibited 'open' forms. By contrast, 'closed' form distracters severely disrupted efficient search performance, indicating that closure can be regarded as a major contributor towards form detection. In conclusion the effects reported may be considered in terms of general mechanisms supporting the rapid extraction of salient regions to guide search.

Introduction

Unit formation can be regarded as a main tool that supports visual information processing in organizing the vast quantity of perceptual information that is continuously extracted from the visual ambient array. Gestalt psychology (Wertheimer, 1923; Koffka, 1935) has long sustained that perceptual organization obeys a series of fundamental rules (i.e. similarity, closure, proximity) according to which information is grouped for subsequent efficient processing. While this concept would entail that units are composed of ‘associated’ fields of elements (Hess & Field, 1999), other approaches assume information processing to start with discrete and separate elements. According to this view, visual perception is conceptualized as a system that begins by analyzing elementary features and progresses by the integration of features into objects under the support of attention (Treisman & Gelade, 1980; Marr, 1982). Psychophysical investigations along this line were able to identify a number of visual ‘primitives’, forming various classes of basic elementary features (i.e. Treisman & Gormican, 1988; Wolfe & Horowitz, 2004).

Classes of basic primitives (i.e. color, orientation) typically correspond to specialized neural analyzers in early visual cortex (i.e. color- or luminance-sensitive cells). However, in extension to such simple feature detectors, analysis of more complex (‘associated’) units has been documented and found to be capable of integrating information without effort. For example, perceptual configurations may be processed with higher efficiency than isolated components (Pomerantz, Sager & Stoever, 1977, see also Treisman & Paterson, 1984). In addition, visual search has shown that component parts may be grouped prior to the engagement of attention (i.e. Rensink & Enns, 1995; Moore & Egeth, 1997), while search is guided more effectively by integrated shapes than corresponding local features (Found & Müller, 1997). In accordance with the formulation of several Gestalt laws (Wertheimer, 1923), experiments investigating the impact of similarity (Duncan, 1984; Duncan & Humphreys, 1989; Humphreys, Quinlan & Riddoch, 1989), closure (Elder & Zucker, 1993; Kovács & Julesz, 1993; Han, Humphreys & Chen, 1999a) and proximity (Han, Humphreys & Chen, 1999b) have shown that early vision operates on the basis of a variety of grouping principles and supports the integration of separate component parts. Thus, visual perception may contain at least some integrated information that is available at early stages of processing.

In general, unit formation is achieved on the basis of similarity and proximity supporting the segregation of distinct regions within the visual field. In extension, closure and collinearity can be regarded as main cues for shape extraction playing an important role in the separation of figures from ground (i.e. Elder & Zucker, 1993; Field, Hayes & Hess, 1993; Kovács & Julesz, 1993). Visual search has demonstrated that the integration of separate collinear elements into a coherent shape supports efficient processing whereas groupings that do not exhibit closure between neighboring fragments are processed inefficiently (Donnelly, Humphreys & Riddoch, 1991; Donnelly, Weekes, Humphreys & Albon, 1998). In one condition, search for a misoriented corner junction could be performed in parallel because distracter junctions could be grouped on the basis of closure and collinearity to form a coherent shape description. By contrast, if identical corner junctions could not be integrated on this basis, search for a misoriented target junction was slow with response latencies being sensitive to the number of candidate distracter junctions. Consequently, it appears that the integration of neighboring segments on the basis of collinearity and closure supports the formation of a coherent shape description.

Besides basic grouping operations that process separate elements and integrate component parts into coherent wholes, certain configurations may be interpreted by the visual system such that the resulting unit does not simply represent the compound of related elements, but defines a qualitatively new emergent figure. Figure 1 contrasts examples of such an illusory emergent figure (Figure 1a; Kanizsa, 1955) with a corresponding grouping that integrates separate elements on the basis of collinearity and closure only (Figure 1b). Whereas Figure 1a appears with a bright central emergent square exhibiting sharp boundaries, Figure 1b does not support a corresponding interpretation.

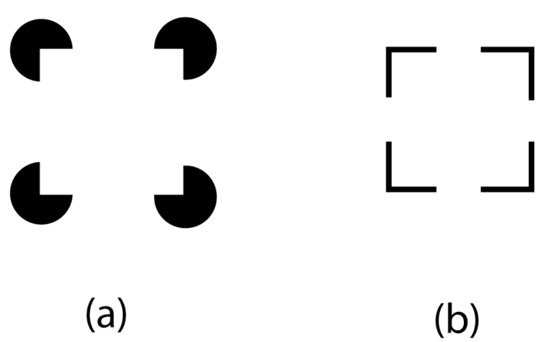

Figure 1 Panel (a) depicts an example of a Kanizsa square inducing an illusory figure. Shown in (b) is a corresponding configuration composed from corner junctions without the emergence of an illusory figure.

Related studies investigating the role of illusory figures in visual search have so far led to equivocal interpretations either suggesting parallel completion of the illusory figure (Davis & Driver, 1994) or stating the contrary, namely that 'there is no evidence that Kanizsa-type contours can be detected in parallel' (Gurnsey, Poirier & Gascon, 1996). Follow-up investigations (see Chapter II) demonstrate an impact of the global form but no impact of the surrounding global contours upon detection of a target Kanizsa figure. Thus, some evidence shows an effect which indicates that the illusory figure is processed for search. However, general principles of grouping as outlined above might provide identical or at least comparable mechanisms without relying on the formation of an illusory figure.

In order to investigate whether grouping operations that support shape integration (closure and collinearity) can account for similar effects as demonstrated for emergent (form) attributes of illusory figures, a series of reaction time (RT) experiments were conducted. Visual search was employed to compare the efficiency of detecting a target upon varying sets of distracter configurations. As has been shown, similarity between targets and distracters can be a major determinant of search efficiency (see Duncan & Humphreys, 1989) leading to inefficient performance for high target-distracter similarity relations and vice versa. Consequently this relation was systematically explored in the current experiments investigating variations of stimulus closure between targets and distracters.

Experiment 6 compared the efficiency of detecting a collinear target square (as in Figure 1b) amongst 'open' and 'closed' form distracters. By systematically analyzing performance for both distracter types, it was shown that closure can be regarded as a major attribute that is coded in search. In extension to this finding, Experiment 7 was performed to investigate the relative effects of reducing closure in both targets and distracters. The results showed a general decrease of performance with a reduction in the specification of neighboring inducer elements. In addition, differences between and within open and closed form conditions were reduced indicating a specific role for closure. Finally, Experiment 8 introduced a reverse manipulation as in Experiment 7, increasing the specification of closure within candidate configurations. By presenting additional perpendicular line terminators for each configuration, responses now revealed a reverse pattern. Both open and closed form distracters showed a strong modulation of the response as a function of closure in distracters. All three experiments show that closure within collinear line segments represents a main cue for the detection of shape configurations. It is concluded that the efficiency of detecting the target depends largely on the specification and the number of candidate - closed shapes, suggesting a specific role for the computation of salient regions in the rapid segmentation of the search display (Stanley & Rubin, 2003).

EXPERIMENT 6

Experiment 6 was performed to investigate the effect of closure in search for configurations composed from L-corner junctions that potentially group to form a completed shape. Observers were presented with search displays that required a speeded response to indicate the presence or absence of a collinear target square configuration among varying sets of distracter arrangements. By applying systematic variations in the composition of distracter configurations, the relative effects upon the efficiency of target detection were investigated. As can be seen from Figure 2a, search displays were varied such that they could either contain potentially conflicting 'closed' or 'open' form configurations (see Figure 2a, I and II, respectively). For both open and closed distracter configurations, the number of collinear continuations was varied (D(0)-D(2), see Figure 2a) increasing the similarity of competing candidate arrangements interfering in the process of target detection. Consequently, a comparison of open and closed form distracters could address the question of whether closure in figural groupings supplies critical information to the process of target detection.

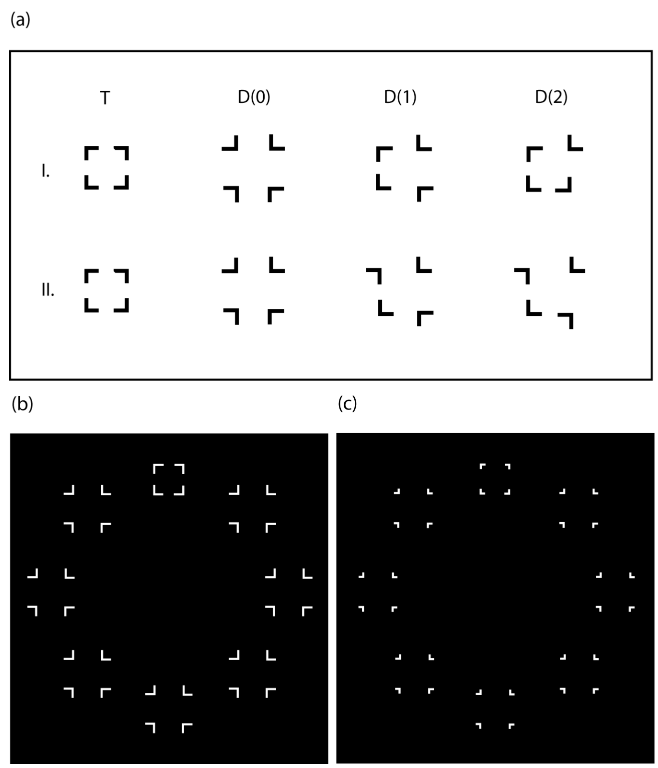

Figure 2 (a) Examples of the collinear square target (T) and distracter configurations presented in Experiment 6. Distracters could contain zero, one or two continuations (D(0) – D(2)) between adjacent corner elements that either promoted a closed form (I) or a corresponding open form (II). (b) Example of a target present display with 8 candidate groupings depicting all possible stimulus locations in Experiment 6. Shown in (c) is a similar display illustrating the 50 % reduction of element specifications as employed for Experiment 7 (see Methods).

Methods

Participants: Eight observers (1 male, mean age = 25.5 years) with normal or corrected-to-normal visual acuity participated in the experiment receiving payment of 8 € (Euro) per hour.

Stimuli: Stimuli were generated by an IBM-PC compatible computer and presented in dark white (1.83 cd m^{-2}) against a black (0.02 cd m^{-2}) background at eight locations arranged in a circle around the center of a 17-inch computer monitor at an eccentricity of 8.75° (see Figure 1b for an example). At a viewing distance of 55 cm, each candidate grouping was composed of four corner junctions with a diameter of 1° and subtended a viewing angle of 2.9 x 2.9°. As depicted in Figure 2a, the target (T) was defined as a collinear square, whereas distracter groupings (D) were obtained by rotating corner junctions so that these could contain zero, one or two aligned continuations that either produced a partially closed form (Figure 2a, I) or a corresponding partial open form (Figure 2a, II). Each trial could contain 1, 2, 4 or 8 candidate groupings presented at random orientations, with a collinear target square present on 50 % of all trials. For display sizes smaller than 8 candidate groupings, stimuli were presented pseudo randomly at the 8 positions illustrated in Figure 2b with restrictions given display sizes of 2, for which candidate groupings were presented at diametrically opposite positions only and given display sizes of 4, for which candidate groupings were presented at every second position of the eight possible display locations.

Procedure: Each trial started with the presentation of a fixation cross for 500 ms at the center of the screen. The fixation cross was then immediately replaced by the search display to which observers responded with a speeded target absent/present response via mouse keys. Displays remained on-screen until a response was given. In case of an erroneous response or a time-out (after 2500 ms), feedback was given by a computer-generated tone and an alerting message presented for 500 ms at the center of the screen. Each trial was followed by an ISI of 500 ms.

The experiment consisted of 2 sessions with 12 blocks containing 80 trials each, resulting in 40 trials per experimental condition. Each session consisted of trials containing open or closed form groupings with separate blocks for each distracter type (D(0)-D(2)) to obtain solid measures for each stimulus condition without conflicting variations from inter-trial transitions. Blocks were administered in pseudo-random order on a subject-by-subject basis.

Results and Discussion

RT analysis: RTs on trials on which a response error (2.3 %) was made were removed from the RT data set prior to analysis. Visual inspection of the RT distribution revealed no pronounced positive skew, which would require the application of correction procedures. Figure 3 presents mean correct RTs and the percentage of errors as a function of display size for each distracter configuration in the open form and closed form condition (columns (a) and (b), respectively). In addition, both responses to open and closed form conditions were compared by means of two repeated-measures ANOVAs computed on the factors *target* (present, absent), display size (*ds*: 1, 2, 4, 8 elements) and collinear continuations (*cc*: 0, 1, 2 continuations).

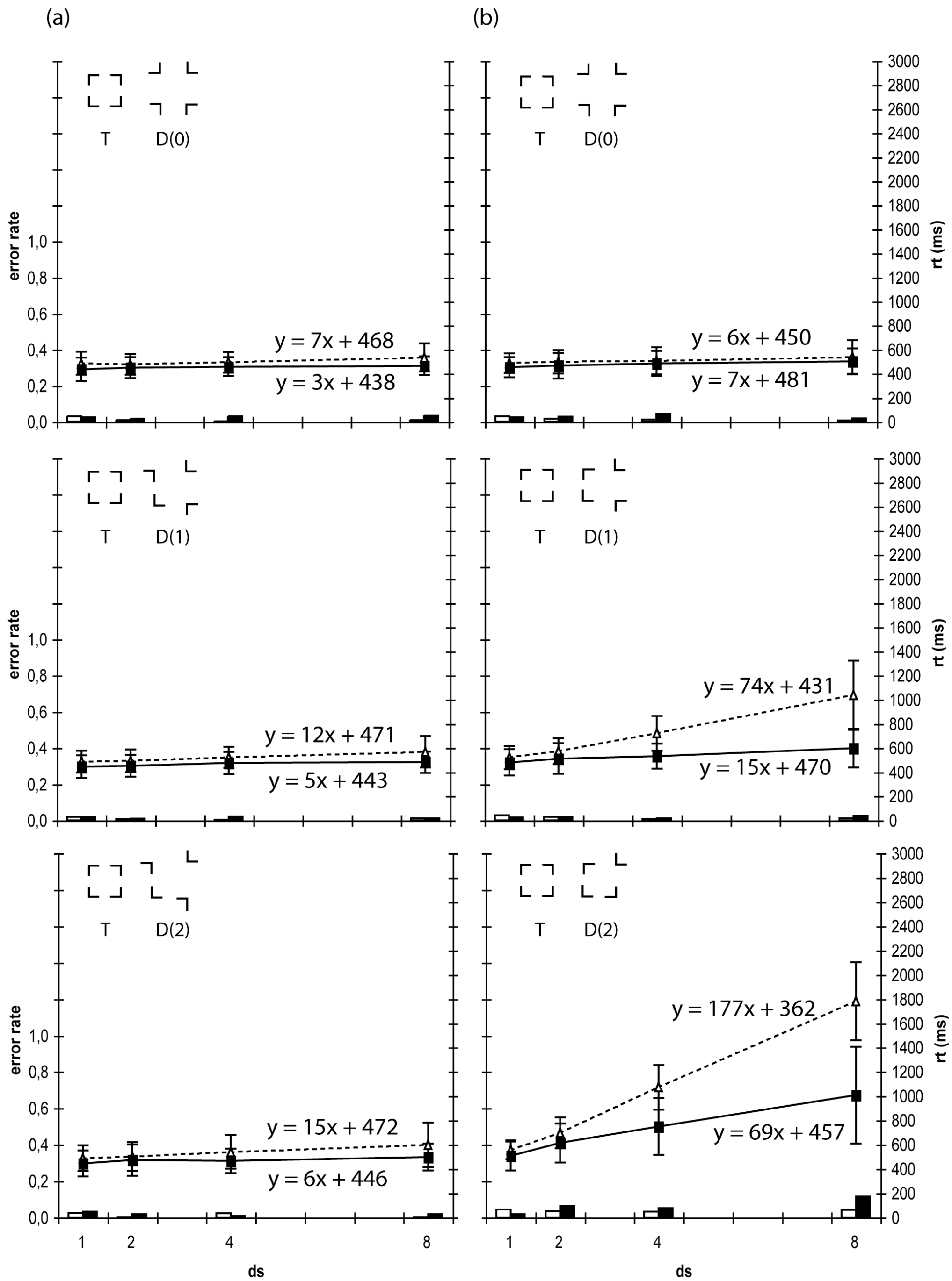

Figure 3 Mean RTs, SDs and associated error rates in Experiment 6 as a function of display size for trials exhibiting open form (a, left column) and closed form information (b, right column) for zero, one or two continuations in distracters, presented in top, middle and bottom graphs, respectively. Each graph shows a prototype target (T) and an example of a distracter grouping (D) and plots RTs, SDs and error rates separately for target absent (dotted line, white bars) and target present trials (solid line, black bars). In addition, the function for the best fitting straight line is given for each reaction time distribution depicting slopes and base rate RTs.

The ANOVA conducted on stimuli that promoted an open form revealed main effects for target and display size [target: $F_{(1, 7)} = 20.74$, $p < .01$; ds: $F_{(3, 21)} = 10.76$, $p < .001$] and the corresponding interaction to be significant [target*ds: $F_{(3, 119)} = 6.39$, $p < .001$]. By contrast, analysis of closed form stimuli resulted in a different outcome. All main effects [target: $F_{(1, 7)} = 72.19$, $p < .001$; ds: $F_{(3, 21)} = 97.61$, $p < .001$; cc: $F_{(2, 14)} = 274.81$, $p < .001$], two-way interactions [target*ds: $F_{(3, 119)} = 64.79$, $p < .001$; target*cc: $F_{(2, 119)} = 55.49$, $p < .001$; ds*cc: $F_{(6, 119)} = 97.28$, $p < .001$] and the three-way interaction were significant [target*ds*cc: $F_{(6, 119)} = 20.11$, $p < .001$] illustrating an increase in RTs for closed form stimuli with increases of collinear stimulus continuations in distracters (see Figure 3b). Thus, search performance markedly decreased leading to steeper display size x target functions with an increase in the closed form distracter specifications. By contrast, no significant three-way interaction (and a corresponding performance decrease) was observable for distracters that promoted an open form (see Figure 3a).

Error analysis: Error RTs tended to be overall slower than correct RTs, and analysis of the probability correct by RT revealed no significant correlation, which argues against the correct data being contaminated by accuracy-speed trade-offs. Arcsine-transformed error rates were analyzed by means of identical repeated-measures ANOVAs to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs.

Analysis of the error data for open form stimulus configurations revealed the target and display size main effects were significant [target: $F_{(1, 7)} = 6.83$, $p < .05$; ds: $F_{(3, 21)} = 5.66$, $p < .01$]. Error rates increased with display size and were more pronounced for target absent conditions. Similarly, errors for closed form configurations where higher for target absent conditions [target: $F_{(1, 7)} = 8.11$, $p < .05$], while the collinear continuations also affected performance [cc: $F_{(2, 14)} = 14.05$, $p < .001$]. In addition, display size interacted with target and collinearity [target*ds: $F_{(3, 119)} = 5.77$, $p < .01$; ds*cc: $F_{(6, 119)} = 4.09$, $p < .001$] illustrating that the closed-form RT increase illustrated above also manifested in increased error rates with an increase in the specification of continuations. Thus, both RT data and error rates showed similar trends indicating clear performance differences between closed and open form conditions. No other significant effects were obtained.

The results of Experiment 6 show a pattern of performance that suggests a specific role of closure for detection of a collinear target square. Displays that presented observers with distracters containing open forms did not have any critical effect on the efficiency of target detection. Consequently, the number of collinear continuations between junctions did not show any statistical significance in the analysis of response latencies and error rates. By contrast, distracter configurations that were presented in the closed form condition had a massive effect interfering with efficient target detection. The specification of one or two collinear continuations between corner junctions in distracters (compare D(0) with D(1) and D(2) distracter types in Figure 3b) resulted in a large effect with increasingly delayed response latencies and higher error rates. Consistent with this finding, the collinear continuations showed a statistical three-way interaction with target and display size, denoting a continuous performance deterioration with an increase in the similarity between targets and distracters (see Duncan & Humphreys, 1989).

Taken together, this asymmetry in performance between open and closed form distracters demonstrates that closure plays an important role for the success of detecting a collinear shape arrangement. While both closed and open form conditions share identical collinear boundaries, similarity-based interference can only be observed when distracters denote closure as a defining property of candidate configurations.

EXPERIMENT 7

Experiment 6 demonstrated that closure in fragmented stimulus configurations plays an important role for detection of the collinear target configuration. In Experiment 7 this influence upon search was reinvestigated by manipulating corner junctions such that the specification of closure for all configurations was reduced. Given that the strength of grouping varies in relation to the ratio of physically specified to total edge length (Shipley & Kellman, 1992), the current experiment investigated how a decrease in the goodness of grouping affects performance. The experiment was basically identical to Experiment 6; except that corner junctions were reduced by 50 % while the overall size of the configuration was held constant (see Figure 2c for an example display). As before, the efficiency in detection of a collinear target square was compared for open and closed form stimulus configurations.

Methods

The experiment was identical to Experiment 6, except that the specification of corner junctions was reduced by 50 %. Consequently, at a viewing distance of 55 cm, each element of a configuration now subtended 0.5°, while the size of the configuration was held constant at 2.9 x 2.9° (see Figure 2c for an example). Eight observers (3 male, mean age = 24.6 years) with normal or corrected-to-normal vision participated in the experiment. All other details were identical to the procedure described in the methods section of Experiment 6.

Results and Discussion

RT analysis: As with Experiment 6, for Experiment 7 RTs on trials on which a response error (4.1 %) was made were removed from the RT data set prior to analysis. Visual inspection of the RT distribution again revealed no pronounced positive skew that would require correction procedures to be applied. Figure 4 presents mean correct RTs and the percentage of errors as a function of display size for each distracter configuration in the open form and closed form condition (columns (a) and (b), respectively). In addition, both responses to open and closed form conditions were compared by means of two repeated-measures ANOVAs computed on the factors *target* (present, absent), display size (*ds*: 1, 2, 4, 8 elements) and collinear continuations (*cc*: 0, 1, 2 continuations).

The RT analysis for open form stimuli with a 50 % reduction of element specifications showed all main effects [target: $F_{(1, 7)} = 71.87$, $p < .001$; ds: $F_{(3, 21)} = 18.18$, $p < .001$; cc: $F_{(2, 14)} = 12.56$, $p < .001$] and two-way interactions to be significant [target*ds: $F_{(3, 119)} = 89.55$, $p < .001$; target*cc: $F_{(2, 119)} = 5.26$, $p < .01$; ds*cc: $F_{(6, 119)} = 2.23$, $p < .05$]. By contrast, analysis of closed form stimuli resulted in a different outcome that replicated Experiment 6. All main effects [target: $F_{(1, 7)} = 71.87$, $p < .001$; ds: $F_{(3, 21)} =$

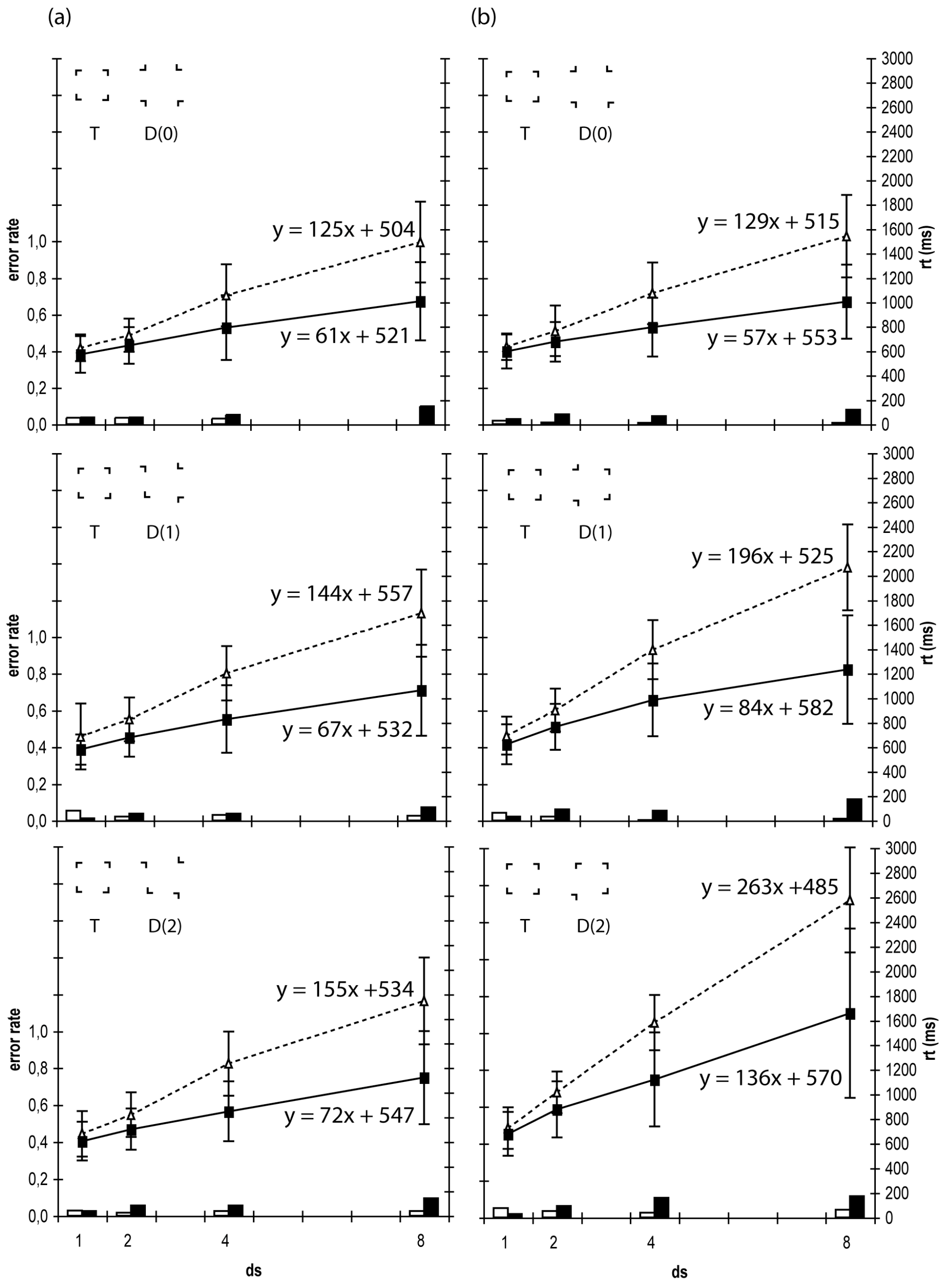

Figure 4 Mean RTs, SDs and associated error rates in Experiment 7 as a function of display size for trials exhibiting 50 % corner specifications of open form (a, left column) and closed form stimuli (b, right column) containing zero, one or two continuations in distracters, presented in top, middle and bottom graphs, respectively. Each graph shows a prototype target (T) and an example of a distracter grouping (D) and plots RTs, SDs and error rates separately for target absent (dotted line, white bars) and target present trials (solid line, black bars). In addition, the function for the best fitting straight line is given for each reaction time distribution depicting slopes and base rate RTs.

53.27, $p < .001$; cc: $F_{(2, 14)} = 185.91$, $p < .001$], two-way interactions [target*ds: $F_{(3, 119)} = 170.17$, $p < .001$; target*cc: $F_{(2, 119)} = 15.07$, $p < .001$; ds*cc: $F_{(6, 119)} = 60.64$, $p < .001$] and the three-way interaction were significant [target*ds*cc: $F_{(6, 119)} = 4.16$, $p < .001$]. Thus, as for the previous experiment, an increase in the specification of the closed form in distracters led to slower responses with steeper display size x target functions (see Figure 4b). However, this modulation of response latencies was less pronounced showing relatively steep slopes not only for the closed form condition but also for open form stimulus configurations. In addition and contrasting with Experiment 6, the open form condition (see Figure 4a) also depicted a moderate modulation of response latencies. Taken together, the reduction of element specifications in Experiment 7 resulted in a general increase of response latencies, while differences between conditions were less pronounced.

Error analysis: As for Experiment 6, error RTs tended to be overall slower than correct RTs, and analysis of the probability correct by RT revealed no significant correlation, which argues against the correct data being contaminated by accuracy-speed trade-offs. As before, arcsine-transformed error data were analyzed by means of identical repeated-measures ANOVAs to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs.

The analysis for open form stimulus configurations showed significant main effects for target and display size [target: $F_{(1, 7)} = 10.70$, $p < .05$; ds: $F_{(3, 21)} = 4.02$, $p < .05$]. In addition, target also depicted significant two-way interactions [target*ds: $F_{(3, 119)} = 15.74$, $p < .001$; target*cc: $F_{(2, 119)} = 3.77$, $p < .05$]. In comparison, errors for closed form stimulus configurations revealed significant effect for all main factors [target: $F_{(1, 7)} = 17.69$, $p < .01$; ds: $F_{(3, 21)} = 4.98$, $p < .01$; cc: $F_{(2, 14)} = 12.12$, $p < .001$] and the interaction between target and display size [target*ds: $F_{(3, 119)} = 13.74$, $p < .001$]. Error rates increased with the specification of collinear arrangements and display size while being more pronounced for target absent conditions. Thus, both RT data and error rates showed similar trends indicating comparable performance patterns for closed and open form conditions. No other significant effects were obtained.

Taken together, the reduction of corner junction specifications in Experiment 7 resulted in a pronounced reduction of search efficiency with prolonged response latencies and higher error rates. In addition, differences between open and closed form conditions were clearly reduced (see Figure 4). Response latencies increased steeply with display size in both cases, while the modulation of RTs as a function of the (closed form) distracter specification was less pronounced. Nevertheless, the ANOVA of RTs still indicated a significant three-way interaction for the closed form condition. In addition, the open form condition also exhibited a slight modulation of RTs as a function of distracter type expressed by significant two-way interactions in the ANOVA of response latencies. Thus, a reduction in the specification of shape inducers resulted in a clear reduction of performance. A comparison of open and closed form stimuli in Experiment 7 shows a substantial reduction of differences between conditions as observed for Experiment 6. Consequently, closure can be regarded as a main factor mediating search performance. Minimizing closure for targets and distracters reduces its potential value for efficient detection of the collinear target configuration.

EXPERIMENT 8

The experiments presented so far have shown that closure within fragmented forms plays an important role in determining the efficiency of search. Experiment 6 indicated a clear asymmetry between closed and open form distracters interfering in detection of a collinear target square. By contrast, Experiment 7 depicted a reduction of this asymmetry for configurations that exhibited a reduction of stimulus closure. By contrast, Experiment 8 was performed to investigate the effect of an increase in stimulus closure. As for Experiment 6, observers had to detect a collinear target configuration within open and closed form distracters. However, to increase the strength of the collinear continuation between neighboring corner junctions, each configuration was displayed with a set of four perpendicular line terminators (see Figure 5 for examples).

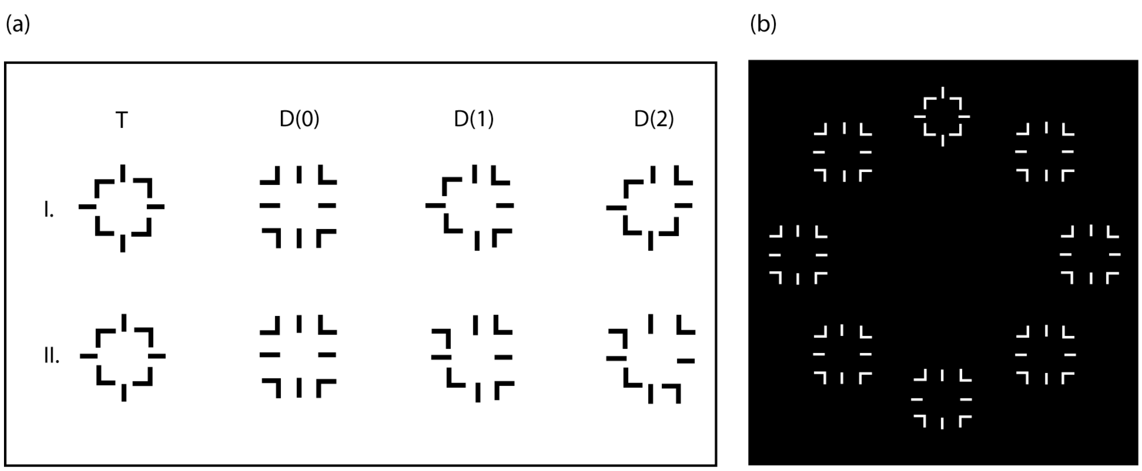

Figure 5 (a) Examples of the collinear square target (T) and distracter configurations providing an increased specification of the salient region by additional collinear line terminations as presented in Experiment 8. Distracters could contain zero, one or two continuations (D(0) – D(2)) between adjacent corner elements that either promoted a closed region (I) or a corresponding open region (II). (b) Example of a target present display with 8 candidate groupings depicting all possible stimulus locations in Experiment 8.

Methods

The experiment was identical to Experiment 6, except that all configurations were now displayed with an additional set of perpendicular line terminators (see Figure 5 for examples). For each stimulus configuration four line terminators subtending 0.5° of visual angle were inserted with perpendicular orientation halfway between each continuation of (collinear) corner junctions. Thus, target and distracter configurations now consisted of four L-corner junctions and four perpendicular line terminators (see Figure 5a). Figure 5b presents an example display illustrating all eight possible stimulus locations. Eight observers (3 male, mean age = 25.7 years) with normal or corrected-to-normal visual acuity participated in the experiment. All other details were identical to the procedure described for Experiment 6.

Results and Discussion

<u>RT analysis</u>: As with previous experiments, for Experiment 8 RTs on trials on which a response error (2.1 %) was made were removed from the RT data set prior to analysis. Visual inspection of the RT distribution revealed no pronounced positive skew that would require the use of correction procedures. Figure 6 presents mean correct RTs and the percentage of errors as a function of display size for each distracter configuration in the open form and closed form condition (columns (a) and (b), respectively). In addition, both responses to open and closed form conditions were compared by means of two repeated-measures ANOVAs computed on the factors *target* (present, absent), display size (*ds*: 1, 2, 4, 8 elements) and collinear continuations (*cc*: 0, 1, 2 continuations between corner junctions).

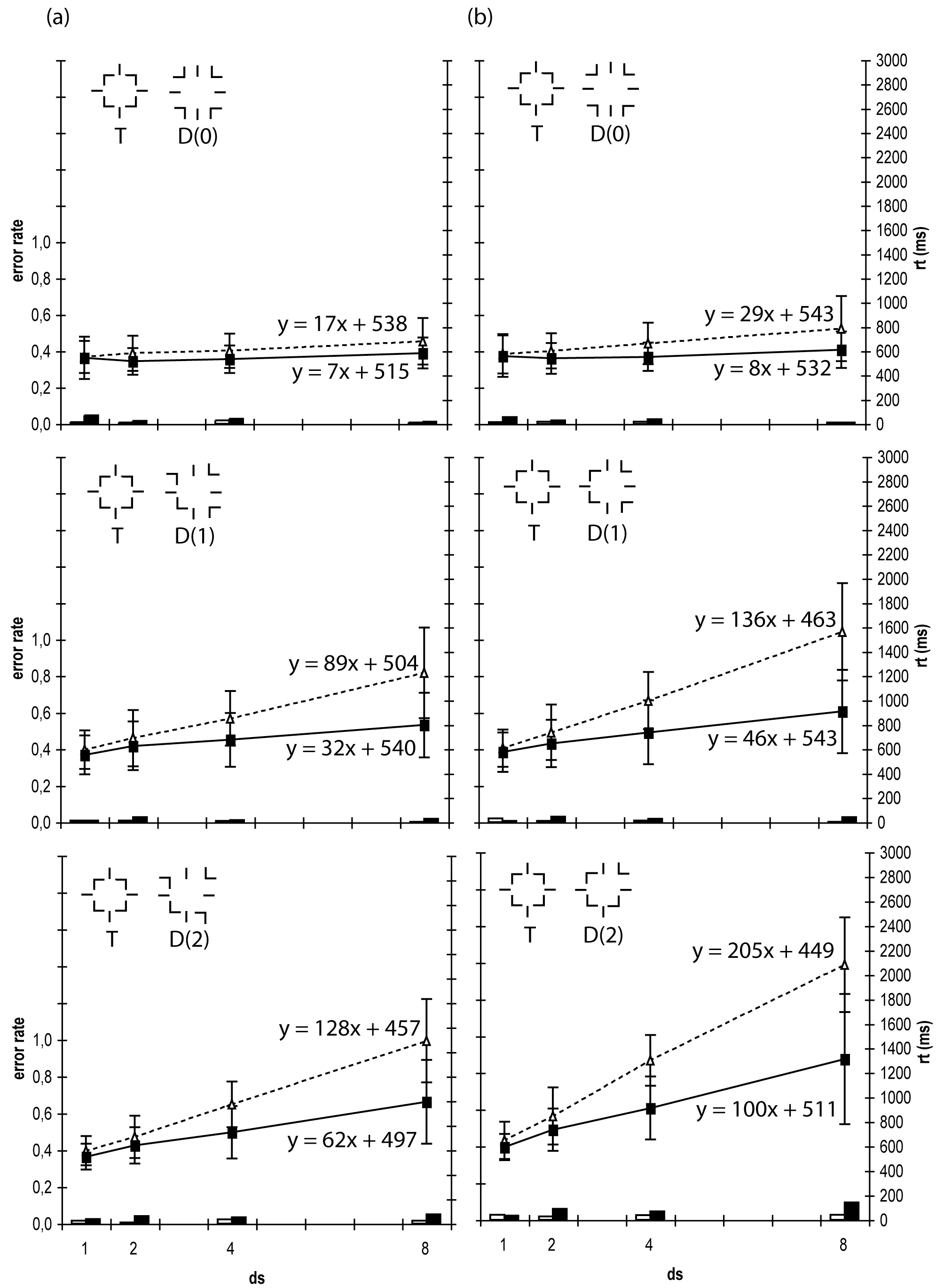

Figure 6 Mean RTs, SDs and associated error rates in Experiment 8 as a function of display size for trials exhibiting an open region (a, left column) or a closed region (b, right column) for zero, one or two continuations in distracters, presented in top, middle and bottom graphs, respectively. Each graph shows a prototype target (T) and an example of a distracter grouping (D) and plots RTs, SDs and error rates separately for target absent (dotted line, white bars) and target present trials (solid line, black bars). In addition, the function for the best fitting straight line is given for each reaction time distribution depicting slopes and base rate RTs.

The RT analysis for open form stimuli with additional perpendicular line terminators showed all main effects [target: $F_{(1, 7)} = 46.62$, $p < .001$; ds: $F_{(3, 21)} = 24.53$, $p < .001$; cc: $F_{(2, 14)} = 15.16$, $p < .001$], two-way interactions [target*ds: $F_{(3, 119)} = 20.41$, $p < .001$; target*cc: $F_{(2, 119)} = 8.91$, $p < .001$; ds*cc: $F_{(6, 119)} = 23.96$, $p < .001$] and the three-way interaction [target*ds*cc: $F_{(6, 119)} = 3.34$, $p < .01$] to be significant. In addition, analysis of closed form configurations depicted a comparable outcome replicating Experiment 6 and 7. As before, all main effects [target: $F_{(1, 7)} = 69.51$, $p < .001$; ds: $F_{(3, 21)} = 99.17$, $p < .001$; cc: $F_{(2, 14)} = 224.89$, $p < .001$], two-way interactions [target*ds: $F_{(3, 119)} = 100.72$, $p < .001$; target*cc: $F_{(2, 119)} = 41.26$, $p < .001$; ds*cc: $F_{(6, 119)} = 115.55$, $p < .001$] and the three-way interaction [target*ds*cc: $F_{(6, 119)} = 13.31$, $p < .001$] were significant. As for previous experiments, the increase in the closed form specification in distracters led to slower responses with steeper display size x target functions (see Figure 6b). However, this modulation of latencies was also present for the open form condition (see Figure 6a), showing that the presentation of additional line terminators led to the interfering effect in both types of distracters.

Error analysis: Again, error RTs tended to be overall slower than correct RTs, and analysis of the probability correct by RT revealed no significant correlation, which argues against the correct data being contaminated by accuracy-speed trade-offs. As for previous experiments, the arcsine-transformed error data were analyzed by means of identical repeated-measures ANOVAs to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs.

Analysis of open form stimulus configurations depicted a significant main effect of target [target: $F_{(1, 7)} = 8.02$, $p < .05$] with increased error percentages for the target absent condition. In addition, errors for closed form stimulus configurations revealed significant main effects for the factors target and contour continuation [target: $F_{(1, 7)} = 9.59$, $p < .05$; cc: $F_{(2, 14)} = 9.79$, $p < .01$]. Also, a significant two-way [ds*cc: $F_{(6, 119)} = 2.48$, $p < .05$] and three-way interaction [target*ds*cc: $F_{(6, 119)} = 2.35$, $p < .05$] showed a modulation of error rates with display size. Thus, both RT data and error rates showed similar trends. Interestingly, only the analysis of error rates could account for differences between closed and open form conditions as reported in previous experiments. The pattern of the analysis showed a larger modulation of errors for the closed form condition. No other significant effects were obtained.

The addition of perpendicular line segments supporting the generation of a collinear continuance had a modulatory effect on both open and closed form conditions. Increasing the specification of closure resulted in a clear modulation of responses for both open and closed form distracters reducing the asymmetry between conditions as described for Experiment 6. As can be seen from Figure 6, closed form distracters basically replicated the findings from Experiment 6. In addition, the open form distracters now also indicated a similar response modulation as a function of the continuity between corner junctions. Since baseline conditions (i.e. trials containing D(0) distracters) for Experiments 6 and 8 both depicted comparable performance patterns showing efficient search, an overall increase in similarity between targets and distracters (manipulated by means of the additional line terminators) can not account for the observed modulation of response latencies. Rather, the outcome from Experiment 8 indicates a specific impact of stimulus closure upon the efficiency of search. The introduction of additional collinear support upon closure in the open form condition of Experiment 8 resulted in a pattern of results similar to closed form configurations emphasizing its critical role for the efficacy of target detection.

General Discussion

The results presented here suggest a specific role for grouping by means of closure in order to integrate collinear line segments to form a coherent shape. Variations in the extent to which closure grouped distracters elements had a clear effect upon the efficiency of detecting the target configuration. Experiment 6 investigated the effects of open and closed form distracters upon detection of a collinear target configuration. The results suggest that interference between targets and distracters can be defined as a function of closure between related elements. Distracters that presented closed form configurations interfered with search whereas distracters that exhibited open form configurations did not have any influence upon performance. In extension to this influence of closure upon search, Experiment 7 investigated the relative effects of a reduction in the strength of shape representations upon performance measures. Configurations were presented with reduced specifications of corner junctions resulting in a reduction of the connection strength between collinear line segments. The results showed that search was less efficient while differences between conditions were clearly reduced. In addition, the modulation of responses as a function of the collinear continuation was less pronounced as compared to Experiment 6. Finally, Experiment 8 investigated the reverse, the effects of an increase in the specification of shape representations by means of closure. The introduction of perpendicular line terminators increasing closure between fragmentary figural information had a modulatory effect on performance in response to both open and closed form stimulus types. As for previous Experiments, the specification of closed form distracters interfered in search as a function of the collinear continuation. Interestingly, an identical modulation of response latencies could now be observed for open form distracters. Consequently, all three experiments reveal a consistent picture suggesting a major role of grouping by means of closure to integrate collinear line segments for the computation of candidate shapes in the process of target detection.

Shape extraction on the basis of grouping by closure as reported for the current experiments stands in close agreement with previous reports. Evidence from texture discrimination tasks (Elder & Zucker, 1993; Field et al., 1993; Kovács & Julesz, 1993) show that closure of bounding contours may be exploited prior to textural analysis in order to segregate a region in two-dimensional space. In addition, evidence from visual search shows that shapes may be combined in parallel to aid target detection (i.e. Treisman & Paterson, 1984; Donnelly et al., 1991; 1998). In line with these outcomes, the current results suggest an important role for closure to extract information in the search process.

The current experiments emphasize closure within collinear line configurations. Results from illusory figures suggest that form attributes play an important role for successful detection performance (see Chapter II). In both cases, similarity-based interference (see Duncan & Humphreys, 1989) was found to vary as a function of shape specificity. For illusory figures, the effect was dependent upon global (i.e. emergent) form information. Collinear line configurations as employed in the current experiments were found to vary as a function of grouping by closure that support bounding of collinear line segments into a coherent shape representation. Consequently, search for both types of stimuli was sensitive to specific aspects of candidate configuration that represented salient attributes to guide successful detection of the target.

A generalization of both types of mechanisms might be drawn from computational models of shape extraction. Within this perspective, the findings of a specific role for closed forms (and emergent forms) in search may be interpreted in terms of a concept of 'salient regions'. Stanley and Rubin (2003) describe salient regions as a set of contiguous image pixels that likely correspond to a major surface in a given scene. While the computation of salient regions might offer a rapid tool for a crude analysis of a visual scene, the current experiments may support the idea that salient regions form a basic representation of a cluttered image that is generated to efficiently guide detection of the required target configuration.

CHAPTER V

Stimulus-dependant task interactions: Detection and identification of illusory figures

Abstract

Detection of a target and the concurrent recognition of target identity represent two fundamental aspects of visual information processing. Evidence from visual search indicates that both tasks are supported by sequential processing stages. In an initial stage, target detection is accomplished by parallel feature analysis. Subsequently, identification of the target is realized by a serial mechanism (Sagi & Julesz, 1985a; 1985b). Here, an attempt was made to investigate the relation between detection and identification in displays that presented target Kanizsa figures embedded within variable sets of distracter configurations. Three experiments show that baseline levels of performance determine whether detection and identification correspond to sequential or interacting processing stages. Inefficient performance resulted in sequential task ordering. By contrast, efficient performance depicted a dynamic interaction between task-related processes. In conclusion, this outcome supports a conception of processing stages for detection and identification that are dynamically adjustable depending on the saliency of the target configuration.

Introduction

Selection and recognition processes comprise two fundamental tasks for the human visual system. Whereas selection processes aim at locating a specific region in space, recognition implies identification of the selected target object. Psychophysical models typically conceptualize both processes within a system that engages at least two sequential stages of processing (Treisman & Gelade, 1980; Marr, 1982). In the first stage, a relevant target location is selected on the basis of salient features. Subsequently, identification of the object at the selected location is accomplished. Psychophysical support for a differentiation of both processes into successive stages has been found when comparing detection and identification tasks (Sagi & Julesz, 1985a; 1985b; Nothdurft, 2002). Whereas simple detection tasks are generally subserved by efficient (i.e. parallel) mechanisms, identification of similar stimuli requires inefficient (i.e. serial) processes.

To investigate performance in selection tasks, visual search techniques have been widely employed. Experiments typically require observers to search for a target embedded within distracters while reaction time (RT) measurements or the processing time per item allows to estimate whether detection was performed efficient or inefficient (Treisman & Gelade, 1980). Within this framework, efficient search performance is interpreted in terms of the parallel allocation of attentional resources across the visual field. Efficient target detection typically depends upon the presence or absence of a salient feature (Treisman & Gormican, 1988; Wolfe & Horowitz, 2004). In addition, corresponding physiological evidence indicates that salient features (i.e. colour, orientation) are coded by specialized analyzers with selective preferences at early stages of visual processing (i.e. colour- or luminance sensitive cells; see Zeki, 1983; Hubel &

Wiesel, 1968). In extension to the parallel detection on the basis of simple features, analysis of more complex units has been found capable of integrating information without effort (i.e. Rensink & Enns, 1995; Moore & Egeth, 1997).

While selection processes focus upon early visual routines that attempt to locate a target, recognition is conceptualized as operating subsequently on the detected target with the aim of identifying it (see Logan, 2002). In agreement with this conception, detection is faster than identification (Nothdurft, 2002). In addition, task comparisons have shown that recognition (identification) of a target requires focal attention. By contrast, simple detection of feature differences is determined by parallel and efficient mechanisms (Sagi & Julesz, 1985a; 1985b). Thus, detection is accomplished at early (parallel) stages of processing whereas identification depends upon later (serial) stages of visual processing. Physiological studies indicate that such late processes supporting the identification of objects may be located in inferotemporal cortex. For example, electrophysiological studies in monkeys have shown specific responses of specialized cells in inferotemporal cortex to complex object attributes (Tanaka, 1996). In addition, firing patterns of inferotemporal neurons can be modulated by object categorizations (Sigala & Logothetis, 2002). Consequently, higher levels of visual processing may provide the basis for the successful identification of a specific object.

To distinguish detection and identification processes experimentally, mental chronometry may offer a framework to decide whether RTs can be decomposed into sequential or interacting stages of processing (Sternberg, 1969; 2001). While additive components between comparisons of detection and identification performance would indicate sequential processing (as in Sagi & Julesz, 1985a; 1985b), a multiplicative relation would point towards task-related interactions without a strict separation of processing stages. While adopting this general framework, the current experiments investigated how processes of selection (i.e. detection) relate to processes requiring the recognition (i.e. identification) of a target object.

In order to address the question of how detection and identification of a target object relate, a series of reaction time (RT) experiments were performed that presented observers with visual search displays containing illusory target Kanizsa figures (Kanizsa, 1955; see Figure 1, T) embedded within varying sets of distracter configurations (see Figure 1, D(rg) and D(ir), for examples). Experiment 9 was performed to obtain baseline measures and to investigate how search for a Kanizsa square target among square distracters (Experiment 9a, see Figure 2a) and search for a Kanizsa diamond target among diamond distracters (Experiment 9b, see Figure 2b) differ. In agreement with previous reports, search for square configurations revealed efficient performance indicating parallel search (Davis & Driver, 1994). By contrast, diamond configurations were dependent upon the number of distracters resulting in inefficient search performance. This suggests that oblique orientations are processed less efficient than horizontal or vertical orientations (see Purghe, 1989). Following this analysis of baseline detection performance within 'simple' displays, Experiment 10 presented observers with displays that combined both square and diamond configurations into 'mixed' displays (see Figure 2c). Performance for mixed displays permitted to introduce two tasks that could be compared. On one hand, detection of a target (square or diamond) was assessed comparable to Experiment 9. In addition, a second task was introduced that demanded the identification of a specific target shape. The results revealed detection performance to be comparable with simple search for diamonds in Experiment 9b. In addition, task comparisons resulted in a robust additive effect (which would be expected from a sequential stage model, see Sternberg, 1969). However, unexpectedly, task comparisons also revealed a robust interaction indicating a dynamic interplay between successive stages of processing. To further asses the robustness of this task interaction, a third experiment was performed in an identical fashion to the second except that distracters now comprised irregular configurations (see Figure 2d), which were expected to slow down performance substantially. Exactly this reduction of efficiency was found. In addition, the interaction between tasks disappeared whereas the additive difference between tasks remained equal. In conclusion, the results presented here demonstrate that high-level (identification) processes interact dynamically with lower levels of visual stimulus analysis related to detection performance. Depending on the saliency of the stimulus material, task differences depict sequential or interacting stages of stimulus processing that are dynamically adjusted for optimal performance (see Di Lollo, Kawahara, Zuvic & Visser, 2001).

EXPERIMENT 9

Experiment 9 was performed to investigate how detection of a target Kanizsa figure varies for different shape descriptions. In Experiment 9a, observers were required to search for a Kanizsa square amongst square distracter configurations (see Figure 1a; T and D(rg), for examples). Conversely, Experiment 9b was performed in an identical fashion, but this time presenting diamond configurations as target and distracters (see Figure 1b; T and D(rg), for examples).

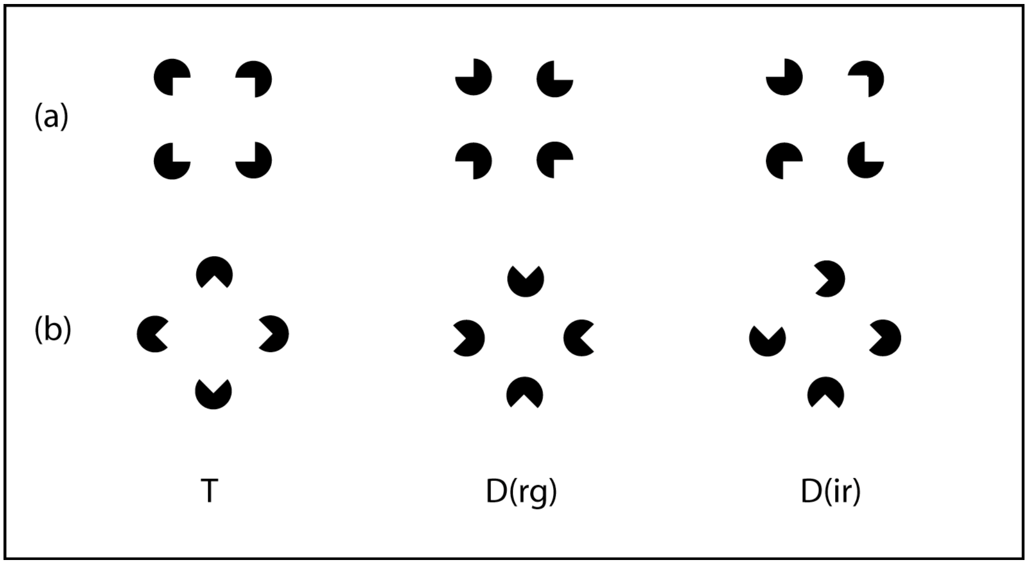

Figure 1 Examples of square (a) and diamond (b) stimulus configurations. The leftmost column shows Kanizsa figures that served as targets (T), middle and rightmost columns depict corresponding examples of 'regular' and 'irregular' distracter configurations (D(rg) and D(ir), respectively).

EXPERIMENT 9A

The experiment was comparable to previous visual search experiments employing Kanizsa figures (Davis & Driver, 1994; Gurnsey, Poirier & Gascon, 1996). Observers were presented with search displays that required a speeded response to indicate the presence or absence of a target Kanizsa square upon varying sets of square distracters.

Methods

Participants: Eight observers (two male; mean age = 27.1 years) with normal or corrected-to-normal visual acuity participated in the experiment receiving payment of 8 Euro per hour.

Stimuli: Stimuli were generated by an IBM-PC compatible computer and presented in dark white (1.83 cd m^{-2}) against a dark (0.02 cd m^{-2}) background at eight locations arranged in a circle and at an eccentricity of 8.75° around the center of a 17-inch computer monitor (see Figure 1b for an example). At a viewing distance of 55 cm, each candidate grouping (composed of four inducing elements with a diameter of 1°) subtended a viewing angle of 2.9 x 2.9°. As depicted in Figure 1a, the target (T) was defined as a Kanizsa square, whereas distracter groupings (D(rg)) were obtained by rotating inducer elements by 180° such that the aperture of each inducing element faced away from the center of each configuration. Each trial could contain 1, 4 or 8 candidate groupings, with a target Kanizsa figure present on 50 % of all trials. For display sizes smaller than 8 candidate groupings, stimuli were presented pseudo randomly at the 8 positions illustrated in Figure 2a with restrictions given display sizes of 4, for which candidate groupings were presented at every second position of the eight possible display locations.

Procedure: Each trial started with the presentation of a fixation cross for 500 ms at the center of the screen. The fixation cross was then immediately replaced by the search display to which observers responded with a speeded target absent/present response via mousekeys. Displays remained on-screen until a response was given. In case of an erroneous response or a time-out (after 2500 ms), feedback was given by a computer-generated tone and an alerting message presented for 500 ms at the center of the screen. Each trial was followed by an ISI of 500 ms.

The experiment consisted of 40 practice trials followed by 8 experimental blocks containing 60 trials each, resulting in 40 trials per experimental condition. Blocks were administered in pseudo-random order on a subject-by-subject basis.

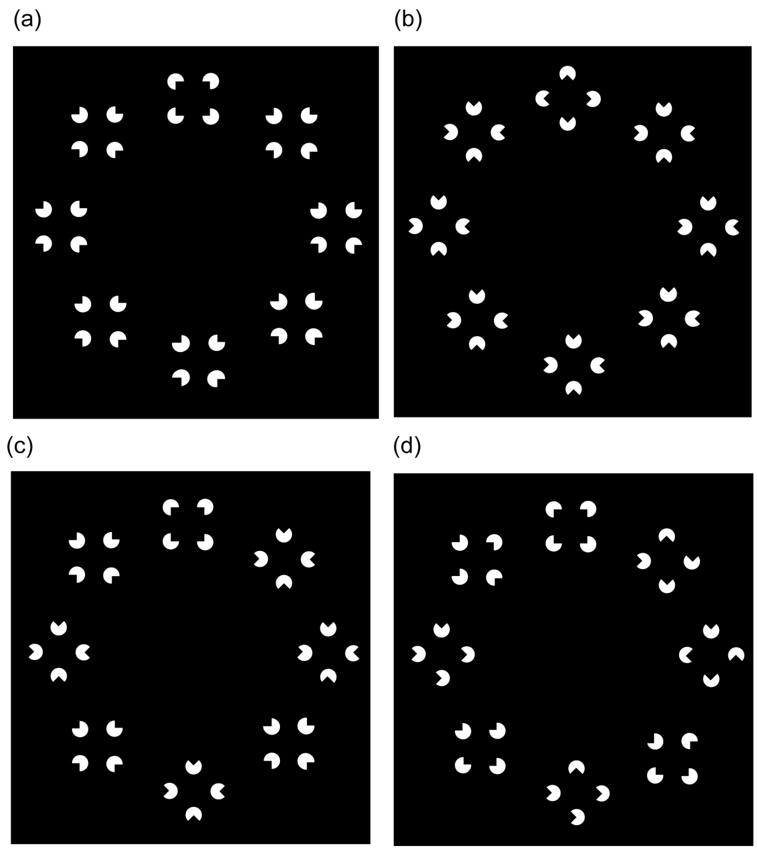

Figure 2 Examples of target present displays containing 8 candidate groupings showing all possible stimulus locations. Search displays consisted of square or diamond configurations presented separately (panels a and b; Experiments 9a and 9b, respectively) contrasting with 'mixed' displays containing both squares and diamonds that were presented with regular (c, Experiment 10) or irregular (d, Experiment 11) distracter configurations.

Results and Discussion

RT analysis: RTs on trials on which a response error (2.5 %) was made were removed from the RT data set prior to analysis. Visual inspection of the RT distribution revealed no pronounced positive skew, which would require the application of correction procedures. Figure 3a presents mean correct RTs and the percentage of errors as a function of display size. In addition, responses were compared by means of a repeated-measures ANOVA computed on the factors *target* (present, absent) and display size (*ds*: 1, 4, 8 elements). The analysis did not reveal any significant effects.

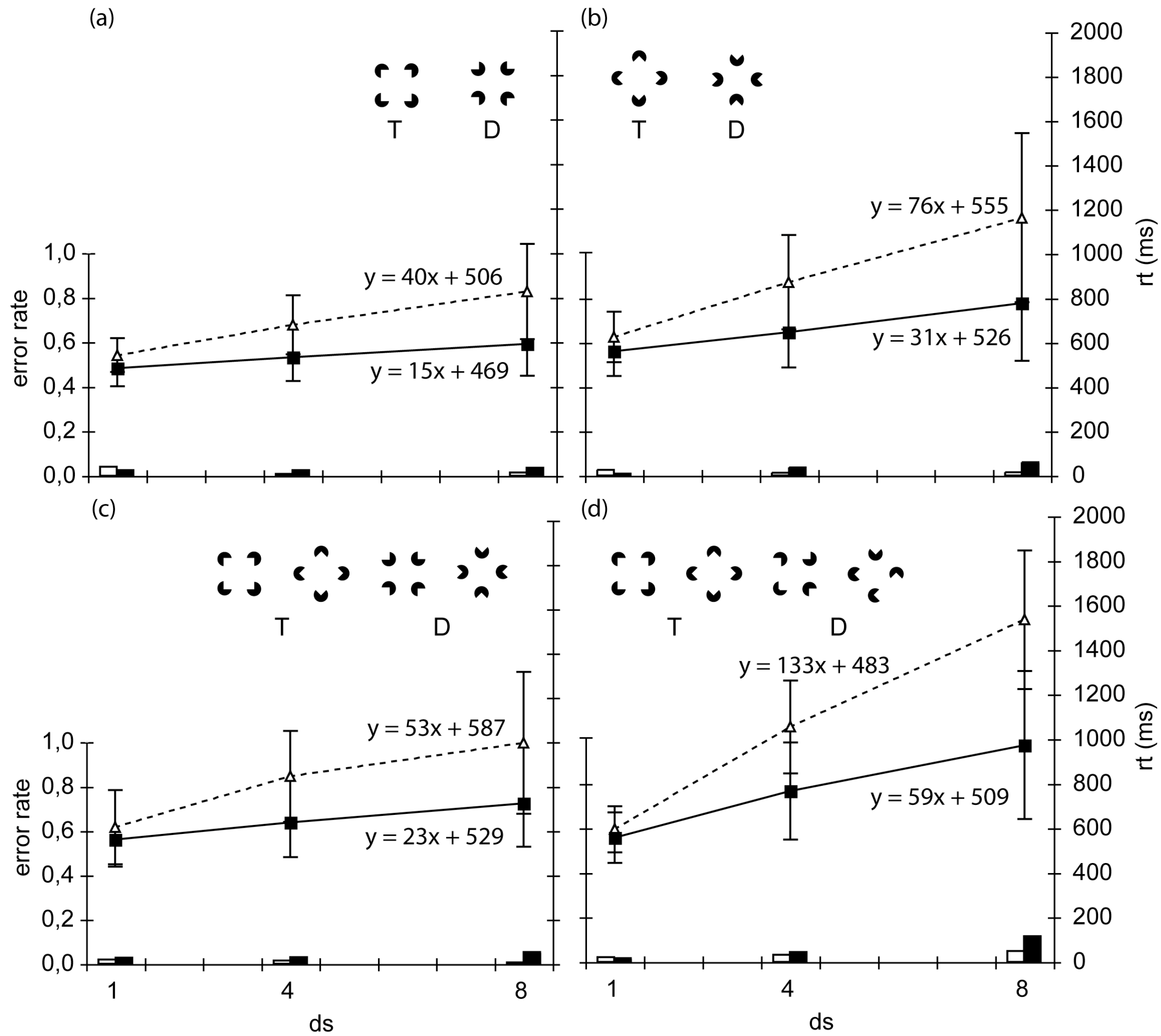

Figure 3 Mean RTs, SDs and associated error rates for the detection task in Experiment 9a (a) and 9b (b), Experiment 10 (c) and Experiment 11 (d) as a function of display size. Each graph shows prototype square/diamond targets and corresponding distracter configurations and plots RTs and error rates separately for target absent (dotted line, white bars) and target present trials (solid line, black bars). In addition, the slope for the best fitting straight line is given for each RT distribution.

Error analysis: Error RTs tended to be overall slower than correct RTs, and analysis of the probability correct by RT revealed no significant correlation, which argues against the correct data being contaminated by accuracy-speed trade-offs. Arcsine-transformed error rates were analyzed by means of identical repeated-measures ANOVAs to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs. As for the RT analysis, no significant effects were obtained.

Experiment 9a provided a pattern of performance that is consistent with results presented by Davis and Driver (1994). Search performance exhibited only moderate slope increases and was (statistically) unaffected by the number of candidate target configurations that were presented. Consequently, this finding supports the interpretation that target Kanizsa squares can be detected in parallel without the engagement of focal attention.

EXPERIMENT 9B

Experiment 9b was identical to Experiment 9a, except that the shape of targets and distracters was modified. Experiment 9a presented observers with square configurations. By contrast, Experiment 9b was performed using diamond configurations.

Methods

The experiment was identical to Experiment 9a, except that all square configurations were replaced by diamond target (Figure 1b, T) and distracter configurations (Figure 1b, D(rg)). Diamonds were obtained by rotating square groupings by 45°. The resulting configuration now subtended 3.9 x 3.9°. An example display is shown in Figure 2b. Eight observers (1 male, mean age = 26.5 years) with normal or corrected-to-normal vision participated in the experiment. All other details were identical to the procedure described in the methods section of Experiment 9a.

Results and Discussion

RT analysis: As with Experiment 9a, for Experiment 9b RTs on trials on which a response error (2.6 %) was made were removed from the RT data set prior to analysis. Visual inspection of the RT distribution revealed no pronounced positive skew. Figure 3b presents mean correct RTs and the percentage of errors as a function of display size. In addition, responses were compared by means of a repeated-measures ANOVA computed on the factors *target* (present, absent) and display size (*ds*: 1, 4, 8 elements). This analysis of RTs revealed a significant interaction effect [target*ds: $F_{(1, 29)} = 5.62$, $p < .05$] showing larger increases in response latencies with display size for target absent responses than for target present responses. No other significant effects were obtained.

Error analysis: Error RTs again tended to be overall slower than correct RTs, and analysis of the probability correct by RT revealed no significant correlation, which argues against the correct data being contaminated by accuracy-speed trade-offs. As before, arcsine-transformed error rates were analyzed by means of identical repeated-measures ANOVAs to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs. As for the RT analysis, the interaction term was significant [target*ds: $F_{(1, 29)} = 13.61$, $p < .01$] indicating that the distribution of errors was identical to the distribution of RTs. No other significant effects were obtained.

Experiment 9b revealed a pattern of results compatible with inefficient search performance. While response latencies and error rates were sensitive to display size, the effect was larger for target absent than present conditions. This outcome contrasts with results obtained from Experiment 9a and consequently supports a different interpretation. Outcomes from previous search experiments that employed Kanizsa triangles (as opposed to squares) also reported a comparable pattern of results (Grabowecky & Treisman, 1989; Grabowecky, Yamada & Strode, 1997). Consequently, not all Kanizsa figure are detected with equal efficiency. Rather, influences such as the oblique orientation of contours in triangles and diamonds are known to negatively affect performance for real (Appelle, 1972) and illusory figures (Purghe, 1989; Ehrenstein & Hamada, 1995). In agreement with these findings, the current experiment indicates that diamonds are harder to detect than squares.

EXPERIMENT 10

Experiment 9 has shown that the efficiency of detecting a target Kanizsa figure depends on the specification of its shape. Detection of squares was more efficient than detection of corresponding diamond configurations. Following this estimation of shape-specific effects, Experiment 10 combined both square and diamond configurations such that 'mixed' displays were presented consisting of both shape descriptions (see Figure 2c for an example display). This manipulation of stimulus factors also permitted variations of task requirements. Two tasks were compared. Performance in a *detection* task (as in Experiment 9) was contrasted with a second task demanding the *identification* of a specific shape configuration.

Methods

Participants: Eight observers (two male; mean age 26.6 years) with normal or corrected-to-normal visual acuity participated in the experiment receiving payment of 8 Euro per hour.

Stimuli: Stimulus configurations were in principle identical to Experiment 9, except that square and diamond configurations were both combined into 'mixed' displays that presented both shape descriptions. As depicted in Figure 1, targets and distracters (T and D(rg), respectively) were defined as squares and diamonds. On a given trial, 1, 4 or 8 candidate groupings were presented with a target Kanizsa square or diamond present on 50 % of all trials. For display sizes of 4 and 8, both square and diamond shape descriptions appeared with equal probability at random locations of the eight-element display shown in Figure 2c. All other stimulus variations were identical to descriptions given for Experiment 9.

Procedure: The experiment consisted of one practice block containing 40 trials and 16 experimental blocks containing 60 trials each resulting in 40 trials per experimental condition. Blocks were administered in pseudo-random order on a subject-by-subject basis. Each block started with a task instruction presented on the monitor ('detection' or 'identification'). The detection task was identical to Experiment 9, requiring a response indicating the presence or absence of a target Kanizsa figure. By contrast, in the identification task a response was required that differentiated between specific target configurations. If a diamond target was present in the search display, observers were asked to respond with their dominant hand. Alternatively, when a square target was presented, a response with the weak hand was required. If there was no target, no response was required and the trial would automatically terminate after 2500 ms. All other details were identical to the procedure described for Experiment 9.

Results and Discussion

RT analysis: RTs on trials on which a response error (3.7 %) was made were removed from the RT data set prior to analysis. Visual inspection of the RT distribution revealed no pronounced positive skew. Analysis proceeded in two steps. First, only detection performance was analyzed comparable to the procedure applied to Experiment 9. Subsequently, target present trials in the detection task were compared to responses in the identification task by means of a second analysis.

In a first step, performance in the detection task was analyzed comparable to the procedure described for Experiments 9a and 9b. Mean correct RTs and the percentage of errors as a function of display size in the detection task are presented in Figure 3c. In addition, responses were compared by means of a repeated-measures ANOVA computed on the factors *target* (present, absent), target *shape* (square, diamond) and display size (*ds*: 1, 4, 8 elements). The analysis revealed all main effects to be significant [target: $F_{(1, 7)} = 67.81$, $p < .001$, shape: $F_{(1, 7)} = 12.63$, $p < .01$, ds: $F_{(2, 14)} = 44.05$, $p < .001$]. In addition, the interaction term between target and display size was significant [target*ds: $F_{(2, 49)} = 43.27$, $p < .001$] with RTs exhibiting a steeper increase for target absence than presence with increasing display size.

In a subsequent step, performance in the detection and identification tasks was compared. For this purpose, target absent responses for the detection task were excluded from data analyses since no corresponding values were available for the identification task. Figure 4a presents the single-subject RT difference related to target identification as a function of the (base rate) latency corresponding to detection performance (see Gegenfurtner, Brown & Rieger, 1997). In addition, responses were again compared by means of a repeated-measures ANOVA computed on the factors *task* (detection, identification), target *shape* (square, diamond) and display size (*ds*: 1, 4, 8 elements). The analysis revealed all main effects [task: $F_{(1, 7)} = 28.94$, $p < .01$, shape: $F_{(1, 7)} = 11.78$, $p < .05$, ds: $F_{(2, 14)} = 55.96$, $p < .001$] and two-way interactions [task*shape: $F_{(1, 49)} = 6.20$, $p < .05$, task*ds: $F_{(2, 49)} = 14.27$, $p < .001$, shape*ds: $F_{(2, 49)} = 4.83$, $p < .05$] to be significant.

Error analysis: Error RTs again tended to be overall slower than correct RTs, and analysis of the probability correct by RT revealed no significant correlation, which argues against the correct data being contaminated by accuracy-speed trade-offs.

Arcsine-transformed error rates in the detection task were again analyzed by means of identical repeated-measures ANOVAs to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs. The analysis revealed the main effect of target [target: $F_{(1, 7)} = 13.88$, $p < .01$] and its interaction with display size [target*ds: $F_{(2, 49)} = 5.33$, $p < .01$] to be significant, comparable to the results obtained for the RT analysis.

In addition, task performance was again compared for detection and identification (excluding target absent conditions in the detection task). Figure 4 presents mean error percentages for squares and diamonds as a function of display size for detection (b) and identification (c). In addition, a repeated-measures ANOVA was computed identical to the procedure applied to the RT data resulting in a significant

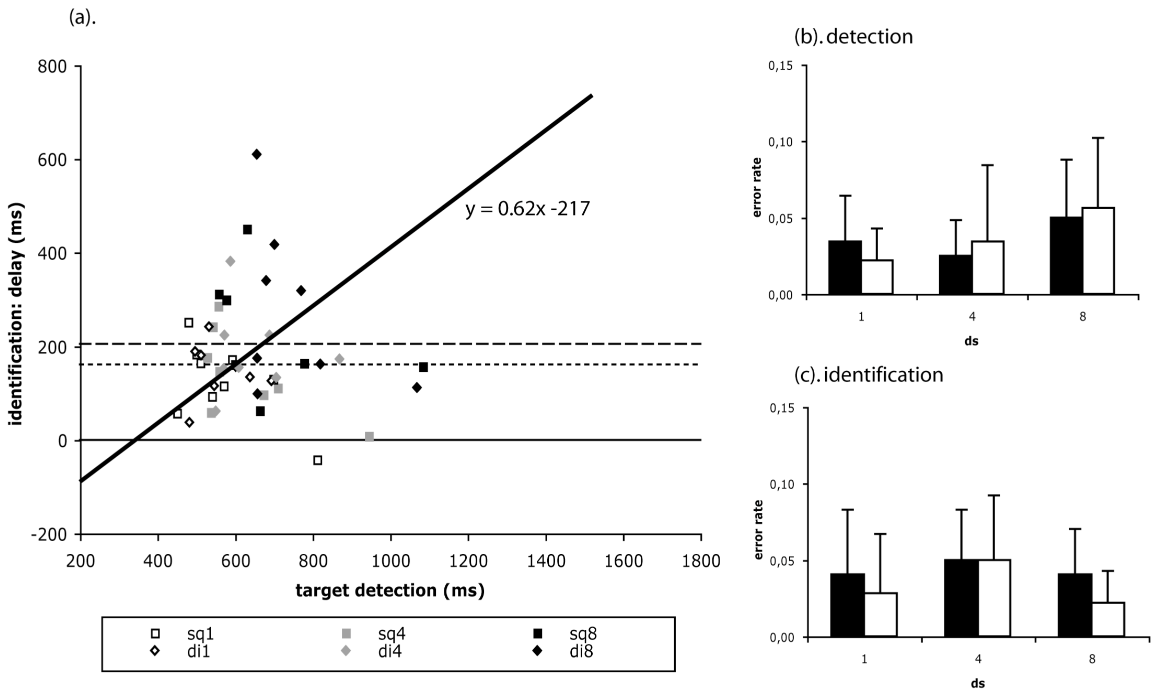

Figure 4 Comparison of single-subject performance for detection and identification tasks in Experiment 10. Panel (a) depicts RTs for the detection task plotted on the x-axis and the associated RT difference between detection and identification response latencies plotted on the y-axis. The thin horizontal line at zero indicates identical detection and identification rates. The dashed and dotted horizontal lines show the observed mean difference between tasks of 153 ms for square and 191 ms for diamond targets. In addition, the diagonal linear approximation plots the function that best describes the scatter of data points. Different symbols describe the shape of the target (square vs. diamond) and set size (white, gray and black symbols for display sizes of 1, 4 and 8, respectively). In addition, shown in panels (b) and (c) are the mean error percentages as a function of display size for square (black bars) and diamond (white bars) responses corresponding to detection and identification.

interaction effect [task*ds: $F_{(2, 49)} = 3.99$, $p < .05$]. No other significant effects were obtained.

In sum, performance for the detection task of Experiment 10 revealed a pattern of results that is comparable to outcomes from Experiment 9b. Search performance was sensitive to display size with larger latency increases in the target absent condition as compared to the target present condition. However, in line with differences obtained for parts a and b of Experiment 9, a significant main effect of target shape indicated that detection of squares was more effective than detection of diamonds. Interestingly, variations of similarity between and within targets and distracters (Duncan & Humphreys, 1989) had no negative effect upon performance in Experiment 10 (as compared to Experiment 9). Rather, the comparable pattern of results for Experiments 9b and 10 (see Figures 3b and 3c) indicates that search depended solely upon the shape of the target configuration but was not affected by the increase in variability of distracter configurations for mixed displays.

In a subsequent step, performance in the detection task was compared to performance in the identification task that was introduced for Experiment 10. As indicated by the dashed and dotted lines (for square and diamond target configurations, respectively) in Figure 4a, mean latencies differed substantially from zero (thick line) resulting in the above described main effect of task. However, the presence of a main effect in isolation would be expected to produce a horizontal distribution of single-subject responses for different conditions. Instead, as can be seen from Figure 4a, differences between conditions were roughly arranged on a diagonal, indicating an interaction (as confirmed by the ANOVA) of tasks with shape and display size.

In summary, Experiment 10 confirmed differences between RTs to different shapes as described for Experiment 9. Furthermore, this effect could be attributed largeley to processes engaged in coding target identity. In addition, the modulation of task settings confirmed serial stage models of processing only partially. As would be expected, the identification of a specific target attribute yielded a robust additive factor which is consistent with the assumption that the visual system first detects a critical target configuration before a response about its identity can be made. However, as shown here, the additive component was also accompanied by a substantial multiplicative interaction that yielded slope increases of approximately 30 percent. Thus, a strict separation of processing stages is difficult to maintain as the data suggest a more dynamic interplay of top-down requirements and bottom-up stimulus related components.

EXPERIMENT 11

Comparisons of task performance for detection and identification revealed not only an additive component related to target identity but also a multiplicative interaction between tasks. The robustness of this interaction was subsequently explored in an experiment that inteded to increase search difficulty while keeping the basic setup of the experiment consistent. Consequently, Experiment 11 introduced an increase in variability of distracter configurations such that search performance was expected to become less efficient.

Methods

The experiment was basically identical to the previous experiment, except that distracter configurations were rotated pseudo-randomly (see Figure 1, d(ir), for examples). An example display is shown in Figure 2d. The manipulation had the effect that inducing elements would create ‘part-goupings’ resulting in an increase of target-distracter similarity (Duncan & Humphreys, 1989) that would potentially lead to interference with efficient target detection. Based on previous findings, this manipulation was expected to slow down search performance severely (see Chapter II). The experiment was performed with eight paid observers (4 male, mean age 24.7 years) with normal or corrected-to-normal vision. All other details were identical to Experiment 10.

Results and Discussion

RT analysis: As for previous experiments, for Experiment 11 RTs on trials on which a response error (5.5 %) was made were removed from the RT data set prior to analysis. Visual inspection of the RT distribution revealed no pronounced positive skew requiring the application of correction procedures. Data analysis followed an identical procedure as described for Experiment 10.

In a first step, performance in the detection task was analyzed comparable to the procedure described for previous Experiments 9 and 10. Mean correct RTs and the percentage of errors as a function of display size in the detection task are presented in Figure 3d. In addition, responses were compared by means of a repeated-measures ANOVA computed on the factors *target* (present, absent), target *shape* (square, diamond) and display size (*ds*: 1, 4, 8 elements). The analysis revealed all main effects to be significant [target: $F_{(1, 7)} = 17.32$, $p < .01$, shape: $F_{(1, 7)} = 15.32$, $p < .01$, ds: $F_{(2, 14)} = 16.68$, $p < .001$], while target also interacted with shape and display size [target*shape: $F_{(1, 49)} = 4.91$, $p < .05$, target*ds: $F_{(2, 49)} = 40.14$, $p < .001$]. Response latencies depicted a steeper increase for target absence than presence. Also, differences between shape descriptions were more pronounced for target present trials.

In a subsequent step, performance in the detection and identification tasks was again compared. As for Experiment 10 in Experiment 11 target absent responses for the detection task were excluded from data analyses since no corresponding values were

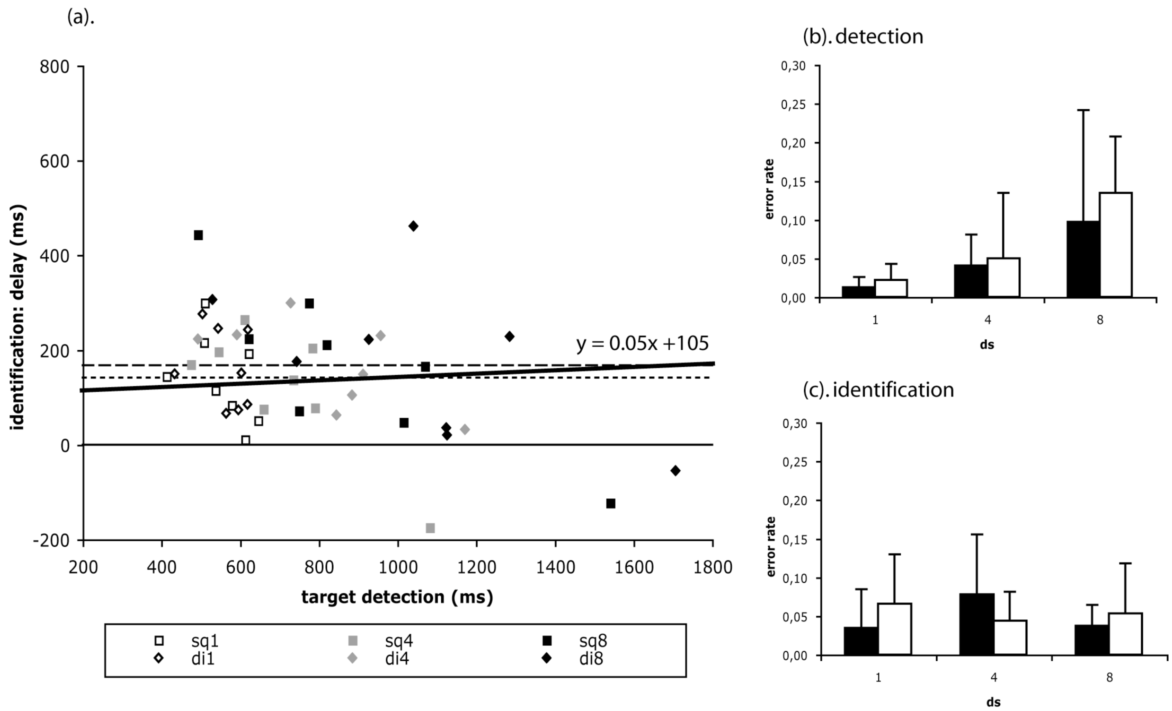

Figure 5 Comparison of single-subject performance for detection and identification tasks in Experiment 11. Panel (a) depicts RTs for the detection task plotted on the x-axis and the associated RT difference between detection and identification response latencies plotted on the y-axis. The thin horizontal line at zero indicates identical detection and identification rates. The dashed and dotted horizontal lines show the observed mean difference between tasks of 141 ms for square and 152 ms for diamond targets. In addition, the diagonal linear approximation plots the function that best describes the scatter of data points. Different symbols correspond to the description given for Figure 4. In addition, shown in panels (b) and (c) are the mean error percentages as a function of display size for square (black bars) and diamond (white bars) responses corresponding to detection and identification.

available for the identification task. Figure 5a presents the single-subject RT difference related to target identification as a function of the latency attributed to detection performance. In addition, responses were compared by means of a repeated-measures ANOVA computed on the factors *task* (detection, identification), target *shape* (square, diamond) and display size (*ds*: 1, 4, 8 elements). The analysis revealed all main effects [task: $F_{(1, 7)} = 17.49$, $p < .01$, shape: $F_{(1, 7)} = 25.58$, $p < .01$, ds: $F_{(2, 14)} = 26.04$, $p < .001$] and the interaction between shape and display size [shape*ds: $F_{(2, 49)} = 14.04$, $p < .001$] to be significant. The interaction indicated that response latencies depicted a steeper increase with display size for diamonds than squares.

Error analysis: Error RTs again tended to be overall slower than correct RTs, and analysis of the probability correct by RT revealed no significant correlation, which argues against the correct data being contaminated by accuracy-speed trade-offs.

Arcsine-transformed error rates in the detection task were again analyzed by means of identical repeated-measures ANOVAs to that applied to the RT data with the object of evaluating any patterning in the production of response errors against trends revealed from analysis of the RTs. The analysis revealed the main effect of target and display size [target: $F_{(1, 7)} = 9.78$, $p < .05$, ds: $F_{(2, 14)} = 5.51$, $p < .05$] to be significant. In addition, target showed interactions with shape and display size [target*shape: $F_{(1, 49)} = 4.36$, $p < .05$, target*ds: $F_{(2, 49)} = 7.62$, $p < .01$], with data patterns comparable to the results obtained for the RT analysis.

In addition, task performance was again compared for detection and identification (excluding target absent conditions in the detection task). Figure 5 presents mean error percentages for squares and diamonds as a function of display size for detection (b) and identification (c) tasks. In addition, a repeated-measures ANOVA was performed to compare error percentages identical to the procedure applied to the RT data. The analysis revealed a significant main effect of display size [task: $F_{(2, 14)} = 6.49$, $p < .05$] and a significant interaction effect [task*ds: $F_{(2, 49)} = 11.38$, $p < .001$] comparable to effects described for RT data. No other significant effects were obtained.

To summarize, analysis of detection performance in Experiment 11 depicted a steep increase in response latencies and error percentages as a function of display size. The results from this experiment reveal the expected breakdown in performance. Presenting irregular distracters that exhibit partial groupings resulted in an increase in the similarity to the target (Duncan & Humphreys, 1989) thereby negatively affecting performance. In addition, the difference between shapes was replicated exhibiting larger response latencies for detection of diamond than square targets.

In contrast to Experiment 10, comparisons of detection and identification tasks revealed no statistical interaction term. In agreement with this finding, the response latencies displayed in Figure 5a depict a horizontal response distribution across conditions. This observation was supported by a robust additive (main) effect in statistical analyses.

In summary, Experiment 11 shows a clear decrease in performance efficiency. In addition, comparisons of detection and identification tasks demonstrate that this increase in search difficulty was accompanied by a switch towards the sequencing of target processing with a clear additive factor differentiating between the two tasks.

General Discussion

The current set of experiments was performed to investigate the relationship between tasks demanding the detection or identification of a target Kanizsa shape. The results revealed an interaction of task specifications and the saliency determining the efficiency of target detection. Identification of salient shapes interacted with early stages of processing associated with detection performance. By contrast, non-salient shape detection and identification was accomplished in a strict serial fashion. Besides this effect of task, for all experiments shape orientations revealed differences that replicate previous findings (i.e. Purghe, 1989).

Baseline measurements in Experiment 9 depicted a clear preference for horizontal and vertical shape orientations. Whereas search for square configurations could be performed independent from the number square distracters (Experiment 9a), diamond targets were sensitive to the number of diamond distracters presented concurrently with the target (Experiment 9b). In agreement with previous search studies that employed Kanizsa figures (Davis & Driver, 1994; Grabowecky & Treisman, 1989; Grabowecky et al., 1997), this finding supports the observed differences in processing of shape orientations for illusory figures (Purghe, 1989; Ehrenstein & Hamada, 1995). Whereas cardinal orientations are detected efficiently, oblique contours lead to inefficient performance. Following this variation of shape information within 'simple' search displays, Experiment 10 introduced 'mixed' displays composed from both square and diamond configurations. Results replicated the effect of stimulus orientation while demonstrating that differences in performance are derived in the main from the specification of the target shape. Shape information in distracters did not interfere with search, even though similarity relations between distracters have been reported to affect performance (Duncan & Humphreys, 1989). In addition, task comparisons in Experiment 10 revealed that detection and identification of a target relate to each other not only by an additive component but also exhibit a multiplicative interaction. Consequently, this finding contradicts assumptions of a clear separation of processing stages (i.e. Sagi & Julesz, 1985a; 1985b). Finally, Experiment 11 was performed in an identical fashion to

Experiment 10. However, to increase the difficulty of detecting the target, distracters now were presented such that partial groupings could emerge; a manipulation which was expected to add a greater degree of interference to target detection. The results revealed exactly this expected breakdown in performance, while the difference between shape orientations could still be replicated. However, contrary to Experiment 10, task comparisons now only exhibited an additive component in isolation suggesting that for inefficient search no interaction between processing stages can be observed.

In summary, the observed pattern of results is consistent with a dynamic adjustment of processing stages. Shape identification in displays containing distracters that share similar attributes with the target leads to sequential stimulus processing (Experiment 11). In a first step, a candidate target configuration is detected. Only in a subsequent step of processing, the identification of the target is accomplished. By contrast, this sequential order of processing stages does not hold for displays that contain distracters that share less salient attributes with the target (Experiment 10). Consequently, detection of the target can already filter incoming information with regards to the categorization needed for subsequent stimulus identification. In agreement with this interpretation, the comparison of tasks in Experiments 10 and 11 depicts either additive components in isolation (Experiment 11) or both additive and multiplicative components in combination (Experiment 10).

The modification of task configurations with stimulus saliency contrasts with previous results that suggest a clear-cut separation between detection and identification (Sagi & Julesz, 1985a; 1985b). Contrasting with this separation of processing stages, the current outcomes indicate that high-level information can be used to dynamically configure the system to obtain an optimum in performance (see Di Lollo et al., 2001). Consistent with this suggestion, physiological studies reported a modulation of early visual areas by task demands (Huk & Heeger, 2000). Thus, early visual areas analyzing specific aspects of each stimulus may be modulated such that the required response is processed with priority. However, this prioritization can only be exploited when specific target attributes (such as the illusory figure) can be segregated efficiently from background noise.

Deutsche Zusammenfassung

(German Summary)

Figur-Bildungsprozesse in der visuellen Suche

(Figural Completion in Visual Search)

Hintergrund

Virtuelle Figuren demonstrieren wie das visuelle System, fehlende Informationen über Lücken im Wahrnehmungsbild hinweg zu integrieren vermag. Die Wahrnehmung von virtuellen Figuren lässt sich dabei nicht einfach als neuronale Fehlfunktion begreifen; sie resultiert vielmehr aus der Fähigkeit des visuellen Systems, unvollständige Objektgrenzen, die häufig in visuellen Szenen auftreten, zu ergänzen. In natürlichen Umgebungen entsteht diese Notwendigkeit der Figurkomplettierung häufig im Zusammenhang mit Objektüberlappungen und sub-optimalen Beleuchtungsbedingungen. Um eine eindeutige Interpretation eines visuellen Wahrnehmungseindruckes liefern zu können muss deshalb sowohl die korrekte Identifikation von einzelnen Merkmalen gewährleistet sein, als auch die Integration von zusammenhängenden Objektteilen stattfinden. Ein Beispiel das verdeutlicht, wie Informationen einzelner Teilkomponenten zu einem integrierten und kohärenten Gesamten zusammengefügt werden, ist die Kanizsa

Figur (Kanizsa, 1955; siehe Abb. 3a, Kapitel I). Diese ist nicht nur durch ‚lokale' Gestalt-Bindungsoperationen zwischen einzelnen Induzierelementen gekennzeichnet, sondern auch durch die Entstehung einer ‚globalen' Figur, welche sich qualitativ vom Hintergrund abhebt. Diese globale (emergente) Figur zeigt dabei Objekteigenschaften, die üblicherweise mit dem Phänomen der virtuellen Figuren assoziiert sind: Eine emergente Figur mit klaren Konturen, Tiefendifferenzen zwischen der virtuellen Oberfläche und den umliegenden Objekten sowie ein Helligkeitsunterschied zwischen der virtuellen Figur und dem Hintergrund ohne ein entsprechendes physikalisches Korrelat zu offenbaren.

Obwohl die relativ einfache, kolineare Anordnung von Induzierelementen bei der Kanizsa Figur zu einem relativ komplexen und plastischen Wahrnehmungseindruck führt, zeigen Einzelzellableitungen aus der Großhirnrinde von Affen, dass relativ frühe Stufen der visuellen Verarbeitung in der Lage sind, eine virtuelle Kontur zu repräsentieren (von der Heydt, Peterhans & Baumgartner, 1984). Wie inzwischen in einer Reihe von Experimenten dargestellt werden konnte, antworten Neurone in den visuellen, kortikalen Arealen V1 und V2 auf virtuelle Konturen innerhalb ihrer rezeptiven Felder in identischer Weise wie auf reale Konturen, die durch einen Luminanzgradienten definiert sind (von der Heydt et al., 1984; Peterhans & von der Heydt, 1991; Lee & Nguyen, 2001). Während vergleichbare Aktivationen in striatalen und extrastriatalen Arealen auch beim Menschen nachgewiesen werden konnten (Ffytche & Zeki, 1996; Murray, Wylie, Higgins, Javitt, Schroeder & Foxe, 2002; Ritzl, Marshall, Weiss, Zafiris, Shah, Zilles & Fink, 2003), zeigten weitergehende Untersuchungen, dass eine zweite wesentliche Quelle der Verarbeitung von virtuellen Figuren im lateralen okzipitalen Komplex, sowie im fusiformen Gyrus liegt (Hirsch, de la Paz, Relkin, Victor, Kim, Borden, Rubin & Shapley, 1995; Stanley & Rubin, 2003; Halgren, Mendola, Chong & Dale, 2003). Frühe Aktivationen in V1 und V2 sind dabei im wesentlichen mit der Verarbeitung von Objektkonturen assoziiert, während spätere Aktivationsmuster auf der Verarbeitung der emergenten Fläche basieren (Stanley & Rubin, 2003). Die Repräsentation von virtuellen Figuren kann daher nicht auf eine einzelne neuronale Quelle zurückgeführt werden. Vielmehr zeigt sich, dass die Verarbeitung von virtuellen Figuren in einer Reihe von Arealen stattfindet, die für die Verarbeitung von Objekteigenschaften im ventralen Pfad verantwortlich sind.

Um einen Bezug zwischen physiologischen Parametern und psychophysischen Maßen der Informationsverarbeitung von virtuellen Figuren herstellen zu können, bestand ein Ansatz darin, zugrundeliegende Objektintegrationsprozesse mit Hilfe von visuellen Suchexperimenten zu untersuchen. Suchexperimente stellen dabei die Aufgabe an Probanden, nach einem bestimmten Zielreiz unter verschiedenen Distraktorreizen zu suchen. Die Reaktionszeit, bzw. die benötigte Verarbeitungszeit pro Objekt erlaubt dabei effiziente von ineffizienter Suche zu unterscheiden (Treisman & Gelade, 1980). Im Rahmen dieses Ansatzes gab es eine Reihe von Untersuchungen, bei denen der Zielreiz als virtuelle Figur definiert und so schnell wie möglich unter einer Reihe von Distraktorkonfigurationen zu entdecken war. Distraktorreize wurden dabei zwar mit identischen Induzierelementen dargestellt, diese wurden aber so präsentiert, dass keine virtuelle Figur entstehen konnte (siehe Beispiele in Abb. 4, Kapitel I). Eine derartige Studie von Grabowecky und Treisman (1989) ergab, dass die Entdeckungsleistung einer Kanizsa Figur von der Anzahl der Distraktoren abhängig ist. Dieses Ergebnis konnte allerdings in einer nachfolgenden Untersuchung (Davis & Driver, 1994) nicht repliziert werden. Stattdessen wurde aufgezeigt, dass die Suche nach Kanizsa Vierecken unter optimalen Bedingungen parallel verläuft. In einer Reihe von Experimenten war die Entdeckungsleistung unabhängig von der Anzahl der Distraktorkonfigurationen im visuellen Feld; ein Ergebnis das im Zusammenhang mit physiologischen Studien (Peterhans & von der Heydt, 1991) als ein Indiz dafür gesehen wurde, dass virtuelle Figuren bereits in frühen Stadien der Informationsverarbeitung kodiert werden.

Die Übereinstimmung von psychophysischen- und physiologischen Parametern wurde in einer Folgeuntersuchung (Gurnsey, Poirier & Gascon, 1996) allerdings ernsthaft in Frage gestellt. In einer Reihe von Experimenten konnte dargestellt werden, dass die An- oder Abwesenheit einer virtuellen Kontur unabhängig von der Sucheffizienz ist. Beispielsweise war die Detektionsleistung einer Kanizsa Figur effizient während die Suche nach einer virtuellen Kontur ähnlich denen in physiologischen Studien (von der Heydt et al., 1984) eine ineffiziente Performanz aufzeigte. Folglich hängt die Sucheffizienz von anderen Faktoren als der An- oder Abwesenheit einer virtuellen Kontur ab. Die Rolle von Figurbindungsprozessen in der visuellen Suche bleibt daher ungeklärt ohne explizit aufzuzeigen, welche Aspekte einer virtuellen Figur in der Suche kodiert werden.

Zusammenfassung der durchgeführten Arbeiten

Die folgenden Experimente wurden mit dem Ziel durchgeführt, die Rolle von Figurbildungsmechanismen in der visuellen Suche zu beleuchten. Dabei wurden sowohl Reaktionszeiten (RZ) als auch ereigniskorrelierte Potentiale im Elektroenzephalogramm

(EEG) analysiert. Nach einer Einführung (Kapitel I) wird zu Beginn der Arbeit in Kapitel II die Frage untersucht, welche Attribute einer virtuellen Kanizsa Figur bei der visuellen Suche kodiert werden. Darauf aufbauend wird in Kapitel III eine EEG Studie vorgestellt, die zeigt, dass die sogenannte N2 Komponente ein physiologisches Korrelat der auf emergenter Forminformation aufbauenden Kanizsa Figurdetektion darstellt. Im Anschluss daran folgen in Kapitel IV Experimente, die statt einer virtuellen Figur den Faktor der Geschlossenheit bei Gestaltgruppierungen variieren und Auswirkungen auf die visuellen Suche bestimmen. Abschließend, und als Ergänzung der Analyse von konfiguralen Faktoren wird in Kapitel V untersucht, wie die Performanz als eine Funktion der Aufgabenanforderungen variiert. Dabei werden Experimente beschrieben, welche die Detektion einer gegebenen Kanizsa Figur mit der Identifikation derselben Figur vergleichen.

<u>Kapitel II</u>: Ausgehend von früheren, uneindeutigen Untersuchungen (Davis & Driver, 1994; Gurnsey et al., 1996) wurden die Arbeiten in Kapitel II mit dem Ziel durchgeführt, kritische Objektattribute in der visuellen Suche nach virtuellen Figuren zu bestimmen. Objektattribute einer Kanizsa Figur wurden dabei auf lokaler- (Induzierelemente) als auch auf globaler Ebene (Kontur und Form; siehe Grossberg & Mingolla, 1985 und Abb. 5, Kapitel I) definiert. Um zu entscheiden, welche dieser lokalen und globalen Attribute überwiegend kodiert werden, wurde eine Reihe von visuellen Suchexperimenten (und darauf bezogenen subjektiven Ratingexperimenten) durchgeführt und systematisch die Ähnlichkeit zwischen Zielreizen und Distraktoren variiert. Der Zusammenhang zwischen Zielreiz-Distraktor Ähnlichkeit (Duncan & Humphreys, 1989) und Sucheffizienz wurde dabei verwendet, um zu entscheiden, welche

globalen und lokalen Attribute mit einer effizienten Entdeckungsleistung interferieren. Unter Verwendung dieser Methode konnte in Kapitel II für die Experimente 1 und 2 gezeigt werden, dass zwar die globale Form, nicht aber die globale Kontur die Entdeckung einer Kanizsa Figur beeinflusst. Zudem ergab sich ein deutlicher Zusammenhang zwischen der Sucheffizienz und der subjektiven Güte der dargebotenen Konfigurationen. Experiment 3 zeigte außerdem, dass lokale Information im Suchprozess nur kodiert wird, wenn entsprechende globale Information im Zielreiz nicht vorhanden ist. Schließlich konnte in Experiment 4 festgehalten werden, dass der zuvor in Experiment 1 beschriebene Einfluss der globalen Form einem graduellen Interferenzeffekt zugeschrieben werden kann.

Kapitel III: Im Anschluss an diese Demonstration einer Asymmetrie zwischen globaler Form und Kontur in der visuelle Suche wurde in Experiment 5, Kapitel III die physiologische Grundlage dieses Effektes untersucht. Ereigniskorrelierte Potentiale wurden in Abhängigkeit von form- und konturbasierten Distraktorinteraktionen bei der Detektion einer Kanizsa Figur analysiert. Dabei zeigten sich spezifische Variationen in der N2 Komponente an Elektroden im lateralen okzipitalen Komplex (LOC). Häufig wird N2 Aktivität als die Zuweisung von attentionalen Ressourcen auf einen ausgewählten Zielreiz interpretiert (Luck & Hillyard, 1994a; Eimer, 1996). Im Kontext der gegenwärtigen Untersuchung lässt sich dieses Ergebnis einer N2 Variation in formsensitiven Arealen als Extraktion von salienten Regionen im Zuge der Zielreizselektion interpretieren (siehe hierzu Stanley & Rubin, 2003).

Kapitel IV: Die bisher in den Kapiteln II und III dargebotene psychophysische und physiologische Evidenz deutet darauf hin, dass die Suche nach einer virtuellen Figur im wesentlichen durch die Spezifikation von virtueller Flächeninformation gesteuert wird. Im Anschluss an diese Untersuchung von Effekten bezüglich der Entstehung von emergenten Figuren, wurde in Kapitel IV untersucht, ob ähnliche Effekte auch für Konfigurationen nachzuweisen sind, deren Elemente ‚nur' auf der Basis von (lokalen) Faktoren wie Geschlossenheit und Kolinearität integriert werden. Analog zu dem Vorgehen in Kapitel II wurden deshalb in Kapitel IV Suchexperimente durchgeführt, bei denen die Effizienz der Zielreizentdeckung in Abhängigkeit von systematischen Variationen der Distraktoreigenschaften untersucht wurde. Statt der bisher verwendeten Kanizsa Figuren wurden nun kolineare Liniensegmente als Zielreize und Distraktoren dargeboten. Ein Vergleich von ‚offenen' und ‚geschlossenen' Distraktortypen in Experiment 6 zeigte diesbezüglich einen Einfluss der Geschlossenheit auf die Effizienz der Zielreizdetektion. In Übereinstimmung mit diesem Befund konnte schließlich in den Experimenten 7 und 8 gezeigt werden, dass die Geschlossenheit einer Konfiguration einen wesentlichen Einfluss auf die Effizienz der Formdetektion aufzeigt. Dementsprechend könnten diese Ergebnisse im Rahmen eines allgemeineren Mechanismus interpretiert werden, bei dem saliente Regionen extrahiert werden um Suchfunktionen zu steuern.

Kapitel V: Die bisherigen Befunde untersuchten im wesentlichen die Bedingungen, welche stimulusbasierte (‚bottom-up') Prozesse bei der Detektion von Figuren eine wesentliche Rolle spielen. Komplementär zu diesen in den Kapiteln II bis IV dargestellten Ergebnissen wurde in Kapitel V untersucht, wie aufgabenabhängige (‚top-down') Prozesse die Performanz beeinflussen. Ausgehend von früheren Befunden wurde die Detektionsleistung mit der Identifikation derselben Zielreizkonfiguration verglichen. Eine einflussreiche Untersuchung von Sagi und Julesz (1985a; 1985b) konnte diesbezüglich zeigen, dass die Detektion einer ersten Verarbeitungsstufe zugeschrieben werden kann, während die Identifikation in einer sequentiell dahinter geschalteten Stufe abgearbeitet wird. Dementsprechend wurde in Kapitel V untersucht, wie die Detektion und Identifikation einer gegebenen Kanizsa Figur zueinander in Relation steht. Drei Experimente wurden durchgeführt. In Experiment 9 wurde eine einfache Detektionsaufgabe präsentiert um eine Schätzung der Basisperformanz für die gegebene Suche zu bekommen. Dabei zeigte sich analog zu früheren Befunden (siehe Purghe, 1989), dass verschiedene Orientierungen einer Figur die Suchleistung beeinflussen können. Im Anschluss daran wurden die Experimente 10 und 11 durchgeführt, um Unterschiede zwischen verschiedenen Aufgabentypen zu untersuchen. Dabei zeigten die Ergebnisse, dass die Salienz des Zielreizes entscheidet, ob Detektion und Identifikation in sequentiellen oder interaktiven Prozessschritten abgearbeitet werden. Während eine ineffiziente Performanz eine sequentielle Aufgabenverteilung aufzeigte, konnte bei effizienter Performanz eine dynamische Interaktion zwischen aufgabenabhängigen Prozessstufen festgestellt werden. Demzufolge unterstützt dieses Ergebnis eine Konzeption von salienzabhängigen, modifizierbaren Stufen der Informationsverarbeitung.

<u>Schlussfolgerungen</u>

Die hier beschriebene, vier Experimentalserien umfassende, Arbeit wurde durchgeführt, um zu untersuchen, wie Objektfragmente in der visuellen Suche integriert werden. Dabei zeigte sich in Übereinstimmung mit anderen Studien (z.B. Rensink &

Enns, 1995), dass die Effizienz der Zielreizdetektion auf der integrierten Repräsentation von Objektfragmenten beruht. In Abhängigkeit von der Spezifikation des Zielreizes werden verschiedene Attribute eines Objektes bevorzugt verarbeitet. Bei Kanizsa Figuren zeigte sich diesbezüglich, dass Suchprozesse auf Basis einer globalen Formrepräsentation ablaufen (Kapitel II; Experiment 1, 2 und 4). Im Gegensatz dazu ließ sich die Effizienz von Suchprozessen bei kolinearen Stimulusanordnungen auf die Geschlossenheit von benachbarten Fragmenten beziehen (Kapitel IV). Bei Zielreizkonfigurationen, die nicht zu einem kohärenten Ganzen zusammengefügt werden, zeigte sich schließlich, dass Suchprozesse relativ langsam und ineffizient sind und von der lokalen Ausrichtung der einzelnen Induzierelemente abhängig sind (Kapitel II, Experiment 3). Für alle drei Zielreiztypen lässt sich demnach festhalten, dass jeweils solche Attribute die Effizienz der Suche beeinflussten, die saliente Objektinformationen vermittelten. Dieser Befund lässt sich im Rahmen eines allgemeineren Segmentationsmechanismus interpretieren, bei dem saliente Regionen extrahiert werden um Suchfunktionen zu steuern (Stanley & Rubin, 2003). In Abhängigkeit der zu entdeckenden Zielreizanordnung werden demzufolge saliente Objektattribute bei der Suche kodiert.

Unterstützung für einen solchen auf der Extraktion von salienten Regionen basierenden Segmentationsprozess konnte außerdem aus der Analyse von ereigniskorrelierten Potentialen bei der Detektion von Kanizsa Figuren gewonnen werden. Die in Kapitel III dargestellte Untersuchung der EEG-Aktivität in Abhängigkeit von form- und konturbasierten Beeinflussungen des Distraktors auf die Zielreizentdeckung zeigte spezifische Effekte für die bereits in Kapitel II beschriebenen, globalen Forminterferenzmechanismen. Diese, in Suchexperimenten beschriebene

Asymmetrie zwischen Form und Kontur, zeigte dementsprechend eine Variation in der N2 Komponente an okzipito-parietalen Elektroden. Im Zusammenhang mit Befunden, die formverarbeitende Mechanismen in topographisch entsprechenden Arealen (z.B. LOC; siehe Murray et al., 2002) lokalisieren konnten, deutet dieser Befund darauf hin, dass die Zielreizdetektion bei Kanizsa Figuren auf identischen Mechanismen beruht. Die Ausrichtung der Aufmerksamkeit lässt sich demnach auf formbasierte, N2-spezifische Variationen im okzipito-parietalen Kortex beziehen.

Der Befund, dass visuelle Suche nach virtuellen Figuren auf der Repräsentation emergenter Forminformation beruht ist auch von Bedeutung bei der Evaluation von früheren, uneindeutigen Studien mit Kanizsa Figuren (Davis & Driver, 1994; Gurnsey et al., 1996). Obwohl erste Befunde einer effizienten Suche nach Kanizsa Figuren im Zusammenhang mit virtuellen Konturantworten in V1 und V2 gesehen wurden (Davis & Driver, 1994), deuteten nachfolgende Untersuchungen keinen solchen Zusammenhang an (Gurnsey et al., 1996). Der in Kapitel II und III gezeigte Forminterferenzeffekt deutet diesbezüglich darauf hin, dass nicht die Kontur verarbeitet wird sondern die entsprechende Flächeninformation, die einen Bezug eher zu ‚Füllmechanismen' in Bereich des LOC aufzeigt als zu V1/V2 Aktivität.

Neben den aufgezeigten Effekten bei virtuellen Figuren konnte ein ähnlicher Einfluss der Ähnlichkeit zwischen Zielreizen und Distraktoren bei kolinearen Gruppierungen aufgezeigt werden. Demnach entspricht die Registrierung von emergenter Forminformation bei virtuellen Figuren der Berechnung von Geschlossenheit bei der Detektion von Liniensegmenten (Kapitel IV). Mit Entsprechungen zu vergleichbaren Befunden (z.B. Elder & Zucker, 1993; Kovàcs & Julesz, 1993) zeigt dieses Ergebnis, dass Geschlossenheit als ein wesentlicher Bestandteil von Formdetektion betrachtet werden kann.

Komplementär zu Attributen, die Relationen zwischen Teilen und Ganzen spezifizieren, konnte gezeigt werden, dass die Entdeckungsleistung auch als eine Funktion der Stimulusorientierung variiert. So konnten die Experimente in Kapitel V zeigen, dass horizontal- und vertikal ausgerichtete Flächen schneller verarbeitet werden als entsprechende diagonale Formen. In Übereinstimmung mit ähnlichen Unterschieden bei früheren Suchexperimenten mit Kanizsa Figuren (Davis & Driver, 1994; Grabowecky, & Treisman, 1989; Grabowecky, Yamada & Strode, 1997) deutet dieses Ergebnis Unterschiede zwischen Orientierungen an, die sowohl bei realen (Appelle, 1972) und virtuellen Figuren (Purghe, 1989) gezeigt werden konnten.

In Kapitel V wurde schließlich auch die Verarbeitung von virtuellen Figuren als eine Funktion des Aufgabentyps untersucht. Während frühere Studien eine sequentielle Abarbeitung bezüglich der Detektion und Identifikation eines Zielreizes annahmen (Sagi & Julesz, 1985a; 1985b; Nothdurft, 2002), konnte die vorliegende Arbeit unter Verwendung von Kanizsa Figuren zeigen, dass die sequentielle Verschaltung abhängig von der Basisperformanz ist. Während eine ineffiziente Aufgabe eine sequentielle Aufgabenabfolge replizieren konnte, zeigte sich für eine vergleichbare aber effizientere Stimulusanordnung eine dynamische Interaktion zwischen aufgabenabhängigen Stufen. Verarbeitungsstufen können daher eher im Sinne eines dynamischen Systems interpretiert werden, welches flexibel auf Gegebenheiten der Umgebung reagiert. Eine strikte Trennung zwischen detektions- und identifikationsspezifischen Stufen konnte hingegen nur teilweise repliziert werden.

Zusammenfassend lässt sich schließlich anhand der Ergebnisse der dargestellten vier Studien festhalten, dass figurale Integrationsprozesse durch eine Reihe von komplexen Operationen auf verschiedenen Verarbeitungsstufen gewährleistet werden (siehe Palmer, Nelson, Brooks, 2003). Einerseits bestimmen Beziehungen zwischen Teilen und entsprechenden Ganzen, welcher Aspekt einer gegebenen Szene die Aufmerksamkeit auf sich zieht. Andererseits, konnte gezeigt werden, dass perzeptuelle Prozesse durch verschiedene Anforderungen formbar sind und somit in einer dynamischen Weise ermöglichen können, eine optimale Leistung zu erreichen.

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