PERGAMON

Vision Research 40 (2000) 1333–1347

Vision Research

www.elsevier.com/locate/visres

The perceptual organization of visual objects: a microgenetic analysis

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Received 19 May 1999; received in revised form 22 November 1999

Abstract

Primed matching was used to examine the microgenesis of perceptual organization for line configurations that vary in the connectedness between their four line components, and for hierarchical patterns composed of four outline closed figures. The results for the line configurations showed that the configural organization of the disconnected line segments was available for priming very early, and its effect outweighed possible effects of the line components. An early relative dominance of the components was observed for the stimuli whose components were closed figures. These results suggest that uniform connectedness is not necessary for the designation of entry-level units. Disconnected line segments are rapidly organized into configurations, provided the presence of collinearity and/or closure. Closed figural elements are individuated early and are grouped into higher-level units with time. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Perceptual organization; Uniform connectedness; Perceptual grouping; Early and late vision

1. Introduction

The visual world consciously perceived is very different from the retinal mosaic of intensities and colors that arises from external objects. We perceive an organized visual world consisting of discrete objects that are coherently arranged in space. Some internal processes of organization must be responsible for this achievement.

The Gestalt School of Psychology was the first to study the problem of perceptual organization. The Gestaltists major contribution to the solution of this problem was the well-known principles of grouping proposed by Max Wertheimer (1955) (originally published in German in 1923): Organization is achieved by grouping elements together according to certain properties present in the image. Wertheimer's principles of grouping include grouping by proximity, by similarity, by good continuation, by common fate, and by closure.

Modern theories of perception assume that organization, based on the Gestalt principles of grouping and figure-ground segregation, must occur at an early, preattentive stage of processing to represent units to which attention is deployed for later processing, including object recognition and identification (e.g. Neisser, 1967; Pomerantz, 1981; Treisman, 1986).

This widely held view regarding the sequence and the temporal order of perceptual processing has been recently challenged (e.g. Palmer & Rock, 1994; Peterson, 1994a; Peterson & Gibson, 1993, 1994a,b). Peterson and her colleagues, for example, found that figure-ground processes are influenced by object recognition processes, and interpreted these results as contradicting the view that figure-ground organization must precede object recognition because it requires a candidate object. Instead Peterson argued for the existence of an early 'prefigural' recognition process that operates before any figure-ground processing.

Palmer and Rock (1994) argued that gestalt grouping may not occur at such an early stage of vision as has been widely assumed because grouping can unify preexisting visual elements, but it cannot account for the creation of such elements. This view is supported by studies demonstrating that grouping works after depth information has been extracted (Rock & Brosgole, 1964), and lightness constancy (Rock, Nijhawan,

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PII: S0042-6989(00)00027-4

Palmer & Tudor, 1992) and perceptual completion (Palmer, Neff & Beck, 1996) have been achieved. There are also findings that suggested that grouping requires attention (Mack, Tang, Tuma, Kahn & Rock, 1992), but other findings, however, demonstrated that certain gestalt grouping does occur under conditions of inattention, albeit without participants conscious awareness of the formed patterns (Moore & Egeth, 1997).

Palmer and Rock (1994) proposed the principle of uniform connectedness (UC) to account for the initial, or the entry-level, organization of the visual field into primitive units. The principle states that a connected region of homogeneous visual properties such as luminance, color, texture, and motion, tends to be perceived initially as a single unit. The processes underlying UC divide the stimulus into discrete regions. The uniformly connected regions are then submitted to figure-ground processes, and the uniformly connected regions that are identified as figures are designated as entry-level units. Once entry-level units are established, grouping and/or parsing processes operate on these units to provide units at superordinate and/or subordinate levels. Thus, Palmer and Rock's (1994) theory does not allow for spatially separated regions to be designated as a single entry-level unit: UC is a necessary (though not a sufficient) condition for the designation of entry-level units. Consider for example the connected and disconnected configurations in Fig. 1. According to Palmer and Rock's theory, the outline diamond in Fig. 1A constitutes a single entry-level unit by virtue of UC. Parsing processes can then divide it into four component lines at the interior concave discontinuities. On the other hand, the theory predicts the designation of the four lines in Fig. 1B as entry-level units because each of the four lines forms a UC region. Grouping processes can then group the four lines into a diamond configuration.

The importance of UC for perceptual organization and visual attention has been demonstrated by the work of Kramer and Watson (1996) and Watson and Kramer (1999). They showed that perceptual judgments were faster when they involved two aspects of a single UC region than when they involved two different UC regions, suggesting that UC may be crucial in defining the units for selective attention.

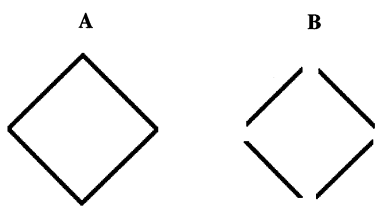

Fig. 1. An illustration of different entry-level units predicted by the principle of UC. The outline diamond (A) constitutes a single entry-level unit by virtue of UC. It can be divided into four component lines at the interior concave discontinuities by parsing processes. The four disconnected line segments (B) constitute entry-level units by virtue of UC of each line. Grouping processes can group the four line segments into a diamond configuration.

Several findings, however, demonstrating the perceptual dominance of configuration even for disconnected line segments (e.g. Pomerantz & Pristach, 1989; Kimchi, 1994; Rensink & Enns, 1995) seem to cast some doubt on the critical role of connectedness in the early organization of visual objects. For example, Rensink and Enns (1995) studied visual search for Mueller–Lyer stimuli and showed that the complete configurations rather than the component segments were available to rapid search. Kimchi (1994) and Kimchi and Bloch (1998) showed that speeded discrimination and classification performance was dominated by the configuration regardless of the discriminability of the line components, both with connected and disconnected stimuli. Although discrimination and classification may be performed on higher-level representations, the possibility that the configuration constitutes the entry-level unit both for the connected and the disconnected stimuli cannot be ruled out.

The global advantage effect, originally demonstrated by Navon (1977); see Kimchi, 1992 for a review), also suggests that for hierarchical patterns of the sort used in the global-local paradigm (as when several spatially separated elements form a configuration), the global structure, rather than the local elements (each of which is a connected figure), is designated as the entry-level unit.

Kimchi (1998) studied the microgenesis of the perceptual organization of hierarchical stimuli that vary in number and relative size of their elements. Results for the many-element patterns indeed indicated an early dominance of global configuration. Individuation of elements occurred later and involved focused attention. The results for few-element patterns, on the other hand, showed an initial representation of the elements along with a weaker representation of global configuration. Grouping of elements into global configuration consolidated with time and involved focused attention.

The present experiments were designed in an attempt to better understand the time course of the perceptual organization of visual objects, and to directly examine the role of UC in the early organization. If connectedness plays a critical role in the designation of entry-level units, then a connected configuration is initially represented in terms of the configuration and the components are available later via parsing processes, whereas a disconnected configuration is initially represented in terms of its components that are later grouped into a configuration.

This hypothesis was examined by studying the microgenesis of the perceptual organization of connected and disconnected line configurations (experiments 1 and 2) and hierarchical patterns composed of a few outline elements (experiment 3), using the primed matching paradigm (Beller, 1971). In this paradigm participants are presented with a priming stimulus followed almost immediately by two test stimuli to match for identity. Positive responses to the test-pair are faster when the stimuli in the test-pair are similar to the prime than when they are dissimilar to the prime. If it is assumed that the internal representation of a visual stimulus develops over time, it is possible, by varying the duration of the prime, to tap earlier and later internal representations (Sekuler & Palmer, 1992; Kimchi, 1998). The logic underlying the present experiments is as follows (see also Kimchi, 1998). At a short prime duration only the entry-level unit of the priming stimulus is represented and acts as a prime. Therefore, responses to test figures that are similar to the entry-level units of the priming stimulus should be facilitated. Superordinate and subordinate units are represented at longer prime durations, facilitating positive responses to test figures that are similar to these units. Thus, if test figures similar to hypothesized entry-level, superordinate, and subordinate units of the priming stimulus are constructed, then responses to such test pairs at different prime durations should reveal information about earlier and later representations of the priming stimulus.

2. Experiment 1

The priming stimuli in the first experiment were line configurations (a diamond and a cross) that varied in connectedness between their line components (no gap, small gap, and large gap, see Fig. 2A,B,C, respectively), and were presented at various durations. There were two types of *same*-response test pairs defined by the similarity relation between the test figures and the prime. The figures in the configuration similarity test-pair were similar to the prime in both configuration and line components, and the figures in the component similarity test-pair were similar to the prime in lines but dissimilar in configuration.

For this set of stimuli, priming effects of the configuration would manifest in facilitation for the configuration similarity condition, and possibly interference for the component similarity condition (due to dissimilarity in configuration). Priming effects of the line components would manifest in facilitation for both similarity conditions (because both types of test pairs are similar to the prime in components).

If UC is necessary for the designation of entry-level units, then early priming effects of configuration (facilitation and inhibition) would be expected only for the connected primes because their configuration is designated as entry-level unit by virtue of UC. The inhibition effect may diminish with time if the line components become available for priming due to parsing processes. For the disconnected primes, on the other hand, early priming effects of the line components would be expected because the lines are designated as entry-level units by virtue of UC. If the configuration is established later by grouping processes, then facilitation would be expected to increase with time for the configuration similarity test-pair, and perhaps to diminish with time for the component similarity test-pair due to interference from prime-test dissimilarity in configuration.

2.1. Method

2.1.1. Participants

Thirty-six students at the University of Haifa participated in this experiment (nine women and three men aged 21–28 in the no-gap condition, eight women and four men aged 20–29 years in the small gap condition, and ten women and two men aged 18–24 years in the large gap condition). All participants had normal or corrected-to-normal vision.

2.1.2. Stimuli

The priming stimuli and the *same*- and *different*-response test pairs are presented in Fig. 2. In addition to the diamond and cross primes a random array of dots was used as a prime. In this case the similarity relation between the prime and the test figures was considered neutral, and served as a baseline condition. Thus, each test type had its appropriate control condition.

Participants sat approximately 60 cm from the screen with their heads resting on a chin rest. From this position each individual line subtended 1.43° of visual angle in length for the diamond and the cross for all primes and test figures. The connected diamond subtended about $2.02° \times 2.02°$, and the connected cross subtended about $2.86° \times 2.86°$. The size of the test figures was identical to that of these primes in all gap conditions. The neutral prime consisted of dots randomly distributed in a matrix that subtended about $2° \times 2°$. The distance between the centers of the two stimuli in a test-pair was 7 cm. The gaps between the lines subtended 0.29° each in the small gap condition, and 1° each in the large gap condition.

2.1.3. Design

The experiment consisted of the factorial combination of six factors in a mixed design: gap (no-gap, small gap, large gap); prime type (diamond or cross); prime duration (40, 90, 190 or 390 ms); priming condition (prime or control); test-pair type (component similarity or configuration similarity), and response (*same* or *different*). The gap factor was between subjects and all the other five factors were within subjects. All the combinations of the five within-subjects factors were randomized within block with each combination occurring on

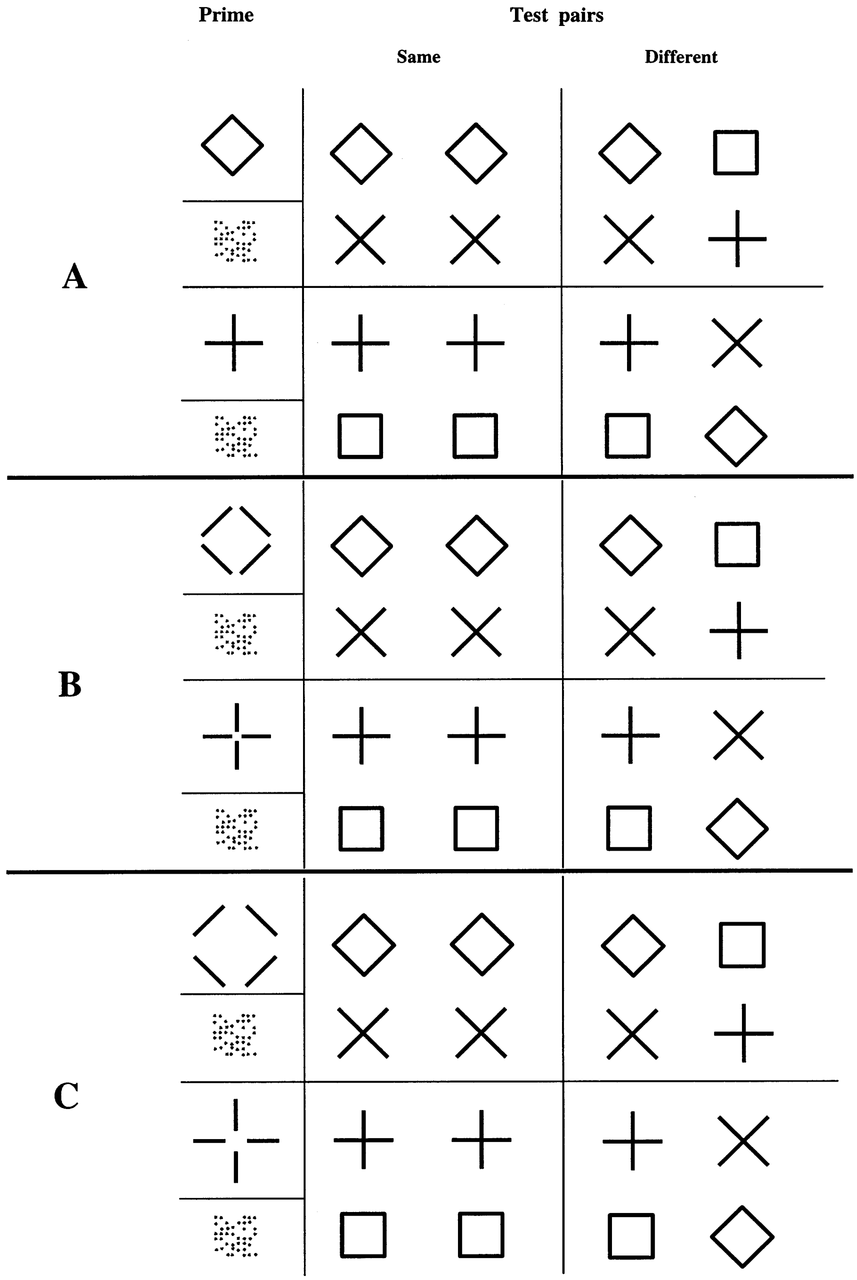

Fig. 2. The priming stimuli and the same- and different-response test pairs used in the (A) no gap condition, (B) small gap condition, and (C) large gap condition, in experiment 1 (when the prime is a diamond made of four oblique lines and the test-pair is two outline diamonds, prime-test similarity is *configuration similarity*; when the test-pair is two Xs, prime-test similarity is *component similarity*. When either of these test pairs is preceded by a random array of dots, prime-test similarity is neutral, providing *configuration control* and *component control*, respectively. When the prime is a cross made of two vertical and two horizontal lines and the test-pair is two outline crosses, prime-test similarity is *configuration similarity*; when the test- pair is two outline squares, prime-test similarity is *component similarity*. When the prime is a random array of dots and the test-pair is either one, prime-test similarity is neutral, providing *configuration control* and *component control*, respectively).

an equal number of trials. The figures in the *different*-response test pairs appeared equally often in each of the two possible locations. For each gap condition there were six blocks of 192 experimental trials each, preceded by a block of 32 practice trials (16 same-response and 16 different-response trials). Two additional trials at the beginning of each test block were warm-up trials.

2.1.4. Procedure and apparatus

Each trial consisted of the following sequence of events. First, a small fixation dot appeared in the center of the screen for 250 ms. After a 250 ms interval a prime (a diamond or a cross configuration) or a random array of dots (the neutral prime) appeared. The presentation time for the priming stimulus was equally and randomly distributed among 40, 90, 190 and 390 ms. Immediately after the presentation of the prime the test display appeared and stayed on until participant responded, for a maximum of 2500 ms. The test display contained two figures presented centrally. At this point, participants had to decide whether the two figures were the same as each other or different from one another.

Participants were told to make each response as quickly and as accurately as possible by pressing one of two keys. Feedback about an incorrect response was provided by presenting an auditory tone as soon as the participant responded. Error trials were retaken at the end of the block. Participants used their dominant hand for the same-response key. Participants controlled the time between blocks by pressing a lever when they were ready to begin the next block.

Stimulus generation and presentation were controlled by a SiliconGraphics Indy workstation. The screen was viewed through the circular aperture (14 cm in diameter) of a matte black cardboard sheet. Responses were made by pressing one of two response keys and response times (RTs) were recorded by the computer. The testing room was dimly lit.

2.2. Results and discussion

All reaction time (RT) summaries and analyses are based on participants' medians RTs for correct responses. Error rates were low (an overall mean of 1.82%), and there was no indication of speed–accuracy tradeoff. Therefore, error rate data are not discussed further.

Fig. 3 shows the mean correct *same* RTs, collapsed across prime type, for component similarity and configuration similarity, as a function of prime duration in the prime and control conditions for each of the gap conditions. Preliminary analyses confirmed that consistent with previous results (e.g. Beller, 1971; Sekuler & Palmer, 1992; Kimchi, 1998), there were no priming effects for the *different* responses. This finding was observed in all the experiments. Therefore, the results reported hereafter refer only to *same* responses. In addition, preliminary analyses confirmed that prime type (diamond or cross) did not interact significantly with priming effects, prime duration, and gap condition. The collapsed data were submitted to a four-factor (gap condition × priming condition × test type × prime duration) analysis of variance (ANOVA) that treated gap condition as a between-subjects factor and the other three factors as within-subjects factors. The analysis showed a significant effect of priming as indicated by the interaction between test type and priming condition, $F(1,33) = 121.15$, $P < 0.0001$. The priming effect varied with prime duration, $F(3,99) = 4.42$, $P < 0.006$, and interacted with gap condition, $F(2,33) = 8.14$, $P < 0.002$.

Planned specific comparisons were carried out to assess the priming effects of configuration and components. Facilitation and inhibition of component similarity and configuration similarity were assessed against the appropriate control condition. These latter comparisons were especially informative because when prime-test similarity in one aspect (e.g. components) entails prime-test dissimilarity in the other aspect (e.g. configuration) two possible effects may contribute to the observed priming effect: facilitation due to prime-test similarity and interference due to prime-test dissimilarity.

As can be seen in Fig. 3, similarity in configuration between the prime and the test figures produced significant facilitation, $F(1,33) = 80.15$, $P < 0.0001$, that increased with prime duration, $F(3,99) = 5.13$, $P < 0.005$, but did not vary significantly as a function of gap condition, $F(2,33) = 1.29$, $P > 0.28$. The facilitation averaged 29 ms in the no-gap condition, $F(1,11) = 33.96$, $P < 0.0001$, 23 ms in the small-gap condition, $F(1,11) = 29.30$, $P < 0.0002$, and 20 ms in the large-gap condition, $F(1,11) = 16.18$, $P < 0.002$.

Similarity in line components between the test figures and the prime produced significant inhibition, $F(1,33) = 48.67$, $P < 0.0001$, that tended to decrease with prime duration, $F(3,99) = 3.32$, $P < 0.05$. The priming effect of component similarity was qualified by a significant interaction with gap condition, $F(2,33) = 5.75$, $P < 0.01$. Significant inhibition was observed for the no-gap condition (averaged 29 ms), $F(1,11) = 30.00$, $P < 0.0002$, and for the small-gap condition (averaged 22 ms), $F(1,11) = 42.28$, $P < 0.0001$. No significant inhibition was observed for the large-gap condition (averaged 5 ms), $F(1,11) = 1.23$, $P > 0.29$. The inhibition in the no gap and in the small gap conditions was observed as early as 40 ms, $F(1,11) = 7.09$, $P < 0.05$, $F(1,11) = 13.81$, $P < 0.05$, for the no gap and small gap, respectively.

For the test figures employed in this experiment, configuration similarity entailed similarity in both components and configuration. One may argue, therefore, that the observed facilitation for the configuration similarity condition was due to similarity in lines rather than in configuration, especially if one assumes that the connected configurations in the test figures are readily divided into four line segments at the interior concave discontinuities (Hoffman & Richards, 1984; Palmer & Rock, 1994). If however, this were the case, then an early facilitation would be expected for the component similarity condition as well. Yet no such facilitation was observed for any of the gap conditions. Rather, the significant inhibition observed for the component similarity condition as early as 40 ms for the no gap and the small gap conditions suggests a strong interference from dissimilarity in configuration. Thus, the observed facilitation for the configuration similarity condition is

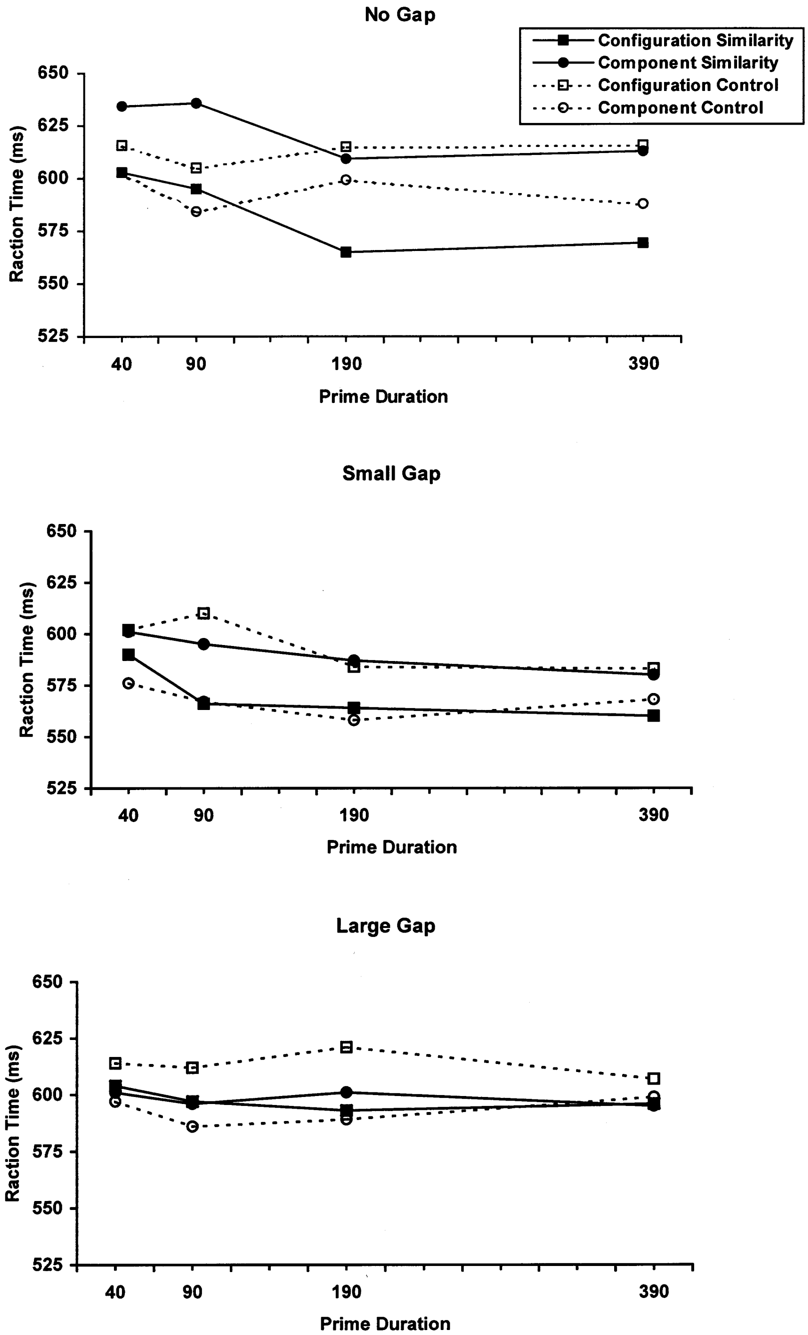

Fig. 3. Mean correct *same* RTs for the component similarity and configuration similarity test pairs as a function of prime duration in the prime and control conditions (collapsed across prime type) for each gap condition in experiment 1.

most likely the result of similarity in configuration, and the observed inhibition for the component similarity condition is most likely due to interference from dissimilarity in configuration between the prime and the test figures, above and beyond any facilitation that could result from component similarity alone.

The pattern of results for the connected primes and for the disconnected primes with small gaps were similar to one another: Similarity in configuration produced facilitation, and dissimilarity in configuration produced a significant inhibition as early as 40 ms. These results indicate that at least for the gap size employed in the small gap condition (0.29°), the configuration of the disconnected line segments was available for priming as early as the configuration of the connected line segments.

When the gaps were larger (1° in size), configuration similarity produced significant facilitation as in the two other gap conditions. Component similarity, on the other hand, produced no significant priming effect.

Presumably, facilitation due to similarity in line components was rebated by inhibition due to dissimilarity in configuration, resulting in a null effect. This pattern of results suggests the early availability of both lines and configuration.

The finding that configuration dissimilarity outweighed component similarity for the small gap condition but not for the large gap condition suggests that proximity plays a role in the early organization of visual objects. Note however, that no facilitation due to component similarity alone was observed even for the large gap condition. This implies that configural organization was present very early even under relatively weak proximity between the line segments, suggesting that UC may not be necessary for the designation of entry-level units.

3. Experiment 2

The results of experiment 1 showed that configural organization was available early in the perceptual organization of disconnected line configurations, even when the gaps between the line components were relatively large.

It is possible, however, that the early availability of configural organization observed in experiment 1 was overestimated for three reasons. One, there was an asymmetry between the two *same*-response test pairs with respect to their similarity relation to the prime: the configuration similarity test-pair was similar to the prime in both lines and configuration, whereas the component similarity test-pair was similar in lines but dissimilar in configuration. This asymmetry could have biased the participants in overreacting to configuration dissimilarity in the component similarity condition. Two, the participants may have been biased toward complete configurations because all the test figures were connected configurations. Three, the two figures in each of the two *different*-response test pairs differed from one another in both components and configuration, so that participants could adopt a strategy of relying only on configural information in making their same/different judgments, thus biasing toward the configuration.[1]

[1] The results of experiment 1 were completely replicated in an experiment in which each of the two figures in the component similarity test pairs was a single line rather than a connected configuration (e.g. a *same*-response test-pair of two oblique lines, and a *different*-response test-pair of an oblique line and a vertical line, for the diamond prime). This replication weakens the arguments concerning potential biases due to connected test figures and to configuration-based same/different judgment. But this experiment introduced another problem, namely that the test figures in the component similarity condition differed from the prime also in number of lines (whereas each of the test figures in the configuration similarity condition included four lines as did the prime). Therefore, experiment 2 provided a better control for the potential biases.

Experiment 2 was designed to control for these potential biases. Both the priming stimulus and the test figures were disconnected configurations so that there were no connected test figures to bias toward complete configuration. The figures in the *same*-response configuration similarity test-pair were similar to the prime in configuration but dissimilar in components, whereas the figures in the *same*-response component similarity test-pair were similar to the prime in components but dissimilar in configuration, so that there was no asymmetry between the two similarity conditions. And finally, one *different*-response test-pair included two figures that differed from one another only in configuration, and the other *different*-response test-pair included two figures that differed from one another only in components (see Fig. 4). This would prevent the participants from adopting a configuration-based strategy in the same/different task.

For this set of stimuli, priming effects of the configuration would manifest in facilitation for the configuration similarity condition and possibly interference for the component similarity condition (due to dissimilarity in configuration). Priming effects of the line components would manifest in facilitation for the component similarity condition and possibly interference for the configuration similarity condition (due to dissimilarity in components). The proximity between the components was relatively strong (small gap, see Fig. 4A) or relatively weak (large gap, see Fig. 4B).

3.1. Method

3.1.1. Participants

Twenty students at the University of Haifa participated in this experiment (five women and five men aged 19–24 years in the small gap condition, and six women and four men aged 20–24 years in the large gap condition). All participants had normal or corrected-to-normal vision.

3.1.2. Stimuli

The priming stimuli and the *same*- and *different*-response test pairs in experiment 2 are presented in Fig. 4.

From a viewing distance of 60 cm each component in the prime subtended $0.76° \times 0.76°$ of visual angle. The overall size of the prime subtended about $1.82° \times 1.82°$ in the small gap condition, and $2.48° \times 2.48°$ in the large gap condition. The gaps between the components subtended 0.29° each in the small gap condition, and 1° in the large gap condition. The neutral prime consisted of dots randomly distributed in a matrix that subtended about $2° \times 2°$. The overall size of the test figures and

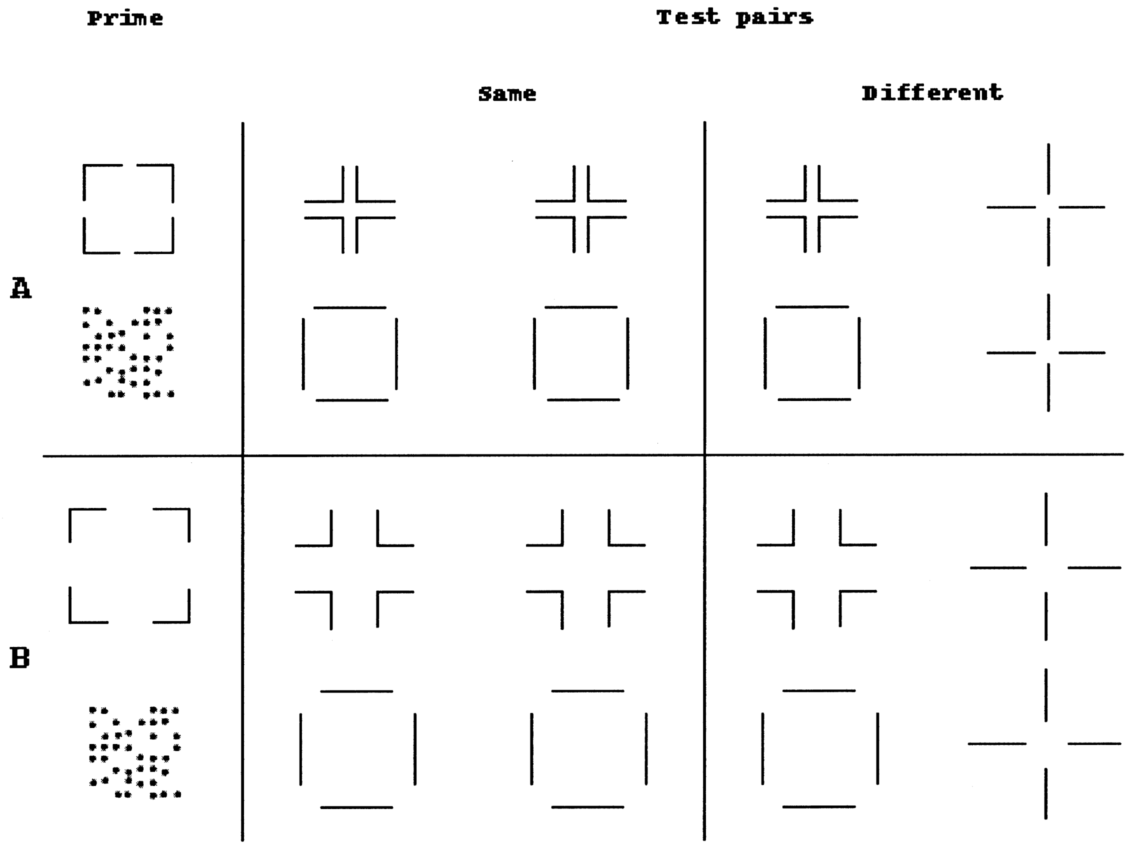

Fig. 4. The priming stimuli and the *same*- and *different*-response test pairs used in the (A) small gap condition, and (B) large gap condition, in experiment 2 (when the prime is a square configuration made of four right-angle junctions and the test-pair is two squares made of two vertical and two horizontal lines, prime-test similarity is *configuration similarity*; if the test-pair is two crosses made of four right-angle junctions then prime-test similarity is *component similarity*. When the prime is a random array of dots and the test-pair is either one, prime-test similarity is neutral, providing *configuration control* and *component control*, respectively).

their gaps were identical to those of the respective prime. Each individual line in the square test figure and in the X test figure subtended about 1.53° in length. The distance between the centers of the two stimuli in a test-pair was 7 cm.

3.1.3. Design

The experiment consisted of the factorial combination of five factors in a mixed design: gap (small gap, large gap); priming condition (prime or control); prime duration (40, 90, 190 or 390 ms); test-pair type (component similarity or configuration similarity), and response (same or different). The gap factor was between-subjects and all the other four factors were within subjects. All the combinations of the four within-subjects factors were randomized within block with each combination occurring on an equal number of trials. The figures in the *different*-response test pairs appeared equally often in each of the two possible locations. For each gap condition there were three blocks of 128 experimental trials each, preceded by a block of 16 practice trials. Two additional trials at the beginning of each test block were warm-up trials.

3.1.4. Procedure and apparatus

The procedure and apparatus were identical to those of experiment 1.

3.2. Results and discussion

Mean correct *same* RTs for the component and configuration similarity as a function of prime duration in the priming and control conditions for each gap condition are presented in Fig. 5. Error rates were low (an overall mean of 1.15%), and there was no indication of speed-accuracy tradeoff. Therefore, error rate data are not discussed further.

A four-factor (gap × test type × prime duration × priming condition) ANOVA (treating gap as a between-subjects factor and the other three as within-subjects factors) for *same* RTs showed a significant effect of priming as indicated by the interaction between test type and priming condition, $F(1,18) = 57.19$, $P < 0.0001$, that did not vary significantly with prime duration, $F < 1$. Priming effect did not interact with gap condition, $F < 1$, and the interaction among priming

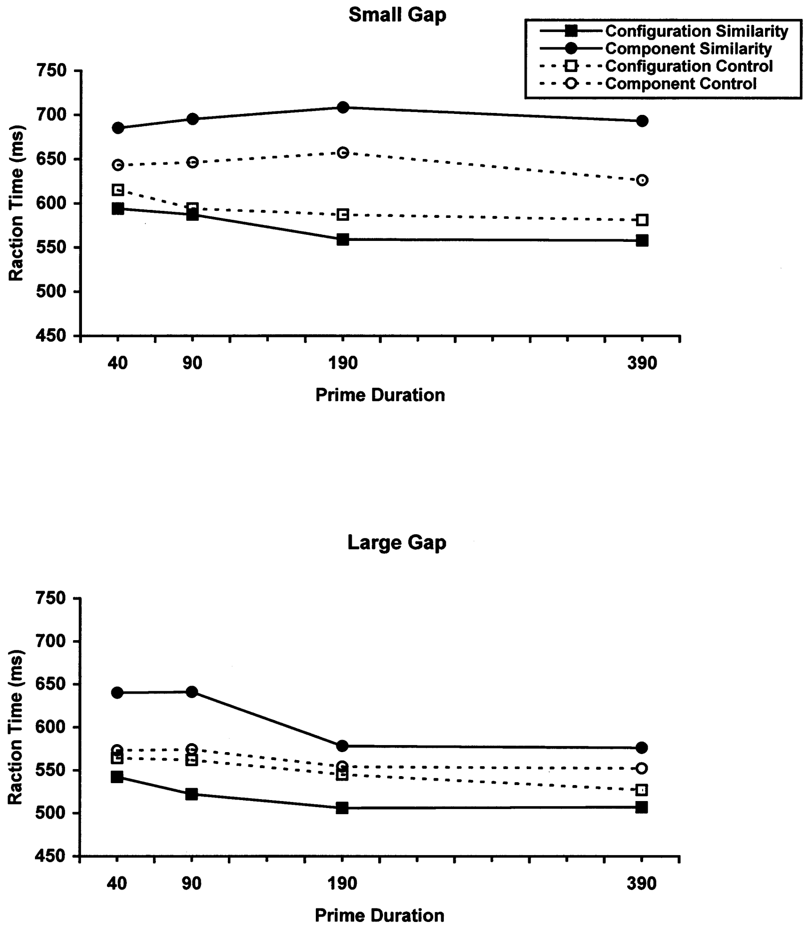

Fig. 5. Mean correct *same* RTs for the component similarity and configuration similarity test pairs as a function of prime duration in the prime and control conditions for each gap condition in experiment 2.

effect, prime duration and gap condition was also not significant, $F(3,54) = 1.51$, $P > 0.22$.

As can be seen in Fig. 5, similarity in configuration between the prime and the test figures produced significant facilitation, $F(1,18) = 25.46$, $P < 0.0001$, that did not vary with prime duration, $F < 1$. Gap size had no significant effect on the facilitation, $F(1,18) = 1.11$, $P > 0.30$. The facilitation effect averaged 19 ms in the small gap condition, $F(1,9) = 10.67$, $P < 0.01$, and 21 ms in the large gap condition, $F(1,9) = 14.84$, $P < 0.01$.

Component similarity produced a significant inhibition, $F(1,18) = 59.86$, $P < 0.0001$, that did not vary significantly with prime duration, $F < 1$. Gap size had no effect on the inhibition effect, $F < 1$. The inhibition averaged 50 ms for the small gap condition, $F(1,9) = 24.98$, $P < 0.0007$, and 45 ms for the large gap condition, $F(1,9) = 37.02$, $P < 0.002$, and it was observed as early as 40 ms, $F(1,9) = 11.78$, $P < 0.01$, for the small gap condition, $F(1,9) = 32.24$, $P < 0.0003$, for the large gap condition. The inhibition effects observed in both gap conditions show that configuration dissimilarity outweighed component similarity, suggesting an early dominance of the configuration regardless of the proximity between the components.[2]

The results of the present experiment converge with those of experiment 1 in demonstrating the early availability of the configuration for disconnected line segments. Since there was no bias toward the configuration in the present experiment this convergence indicates that the early availability of the configuration observed in experiment 1 for both the connected and the disconnected primes is not likely to be due to any bias. Taken together, the results of experiments 1 and 2

[2] It is interesting to note that although strong subjective contours of a cross are experienced in the primes of experiment 2 (see Fig. 4), so that in fact the component similarity test figures were similar to this illusory cross, still a strong inhibition effect was found for this condition. This finding suggests that the dominant percept, at least in the first few hundred milliseconds of processing is the completed ‘occluded’ configuration, rather than the subjective ‘occluding’ surface. This in turn may suggest that perhaps the subjective surface, and thereby its contours, is a consequence of amodal completion of incomplete figures, as proposed by Kanizsa (1979) (but see Day & Kasperczyk, 1983, and Purghe & Coren, 1992).

suggest that UC is not necessary for the designation of entry-level units.

There is however, some discrepancy between the present results and those of experiment 1: proximity between the line segments had an effect on the relative dominance of configuration and components for the stimuli used in experiment 1, but not for the stimuli used in the present experiment. The effect of proximity in experiment 1 manifested in the priming effect for the component similarity condition: component similarity produced a significant inhibition (attributed to configuration dissimilarity) for the no gap and small gap conditions, but not for the large gap condition.

A possible account of the difference between experiment 1 and the present experiment regarding the effect of proximity refers to the way proximity may interact with other grouping factors, in particular closure and collinearity. The priming stimuli in the present experiment possess closure and collinearity. The priming stimuli in experiment 1, on the other hand, possess either closure (the diamond prime) or collinearity (the cross prime). It is quite possible that proximity interacts differently with each of these factors alone than with their combination, so that the combination of closure and collinearity dominates proximity, but each factor alone does not. That is, proximity between components has less than an effect when closure and collinearity are combined (as in the primes of experiment 2) than when only closure is present (as in experiment 1, diamond prime) or when only collinearity is present (as in experiment 1, cross prime). Consequently, strong proximity facilitated grouping by either closure or collinearity more than weak proximity, but no effect of proximity was observed when closure and collinearity were combined. Some evidence for the potential power of the combination of closure and collinearity over closure alone comes from the work of Donnelly, Humphreys and Riddoch (1991) who demonstrated that the combination of closure and collinearity resulted in an efficient visual search, much more so that in the absence of collinearity.

4. Experiment 3

The priming stimuli in experiments 1 and 2 were configurations consisting of four line segments. The main finding was the early dominance of configural organization. Previous findings by Kimchi (1998), on the other hand, showed an early relative dominance of the components for hierarchical stimuli composed of four relatively large elements, whereas an early dominance of the configuration was found only for stimuli composed of many, relatively small elements. The discrepancy between the present results and previous results for few-element patterns (Kimchi, 1998) might be attributed to a difference in the 'nature' of the components: The components in the present experiments were open-ended line segments whereas the components in Kimchi's (1998) experiment were (closed) solid shapes (circles and squares). Alternatively, this discrepancy may be due to a difference in the salience of the components: black solid shapes in Kimchi's (1998) experiment versus thin line segments in the present experiments. Perhaps it is simply this difference in salience that accounts for the difference in the relative dominance of components and configuration. In order to examine this possibility experiment 3 studied the microgenesis of the perceptual organization for patterns composed of four outline shapes for which the difference in salience in comparison to the line segments in experiments 1 and 2 was minimized. The gaps between the elements varied (small gaps versus large gaps, see Fig. 6A,B, respectively).

4.1. Method

4.1.1. Participants

Twenty-four students at the University of Haifa participated in this experiments (ten women and two men aged 20–28 years in the small gap condition, and eight women and four men aged 19–24 years in the large gap condition). All participants had normal or corrected-to-normal vision.

4.1.2. Stimuli

The priming stimuli and the *same*- and *different*-response test pairs are presented in Fig. 6. From a viewing distance of 60 cm each circle element in the prime subtended 0.76° of visual angle in diameter. The overall size of the prime subtended about 1.82° × 1.82° in the small gap condition, and 2.48° × 2.48° in large gap condition. The distance between the components subtended 0.29° each in the small gap condition and about 1° each in the large gap condition. The neutral prime consisted of dots randomly distributed in a matrix that subtended about 2° × 2°. The overall size of the test figures, the size of their elements, and the distance between the component were identical to those of the respective prime. The distance between the centers of the two stimuli in a test-pair was 7 cm.

4.1.3. Design, procedure and apparatus

The design, procedure, and apparatus were the same as those of experiment 2.

4.2. Results and discussion

Mean correct *same* RTs for component and configuration similarity as a function of prime duration in the priming and control conditions for each gap condition are presented in Fig. 7. Error rates were low (an overall mean of 1.84%), and there was no indication of speed-accuracy tradeoff. Therefore, error rate data are not discussed further.

A four-factor (gap × test type × prime duration × priming condition) ANOVA (treating the gap as a between-subject factor and the other three as within-subjects factors) showed a significant priming effect, $F(1,22) = 19.84$, $P < 0.0002$, that varied significantly with prime duration, $F(3,66) = 4.67$, $P < 0.01$, but did not vary significantly as a function of proximity between the components, $F < 1$. The effect of prime duration on the priming effect was also the same for the two gap conditions, $F < 1$.

As can be seen in Fig. 7, similarity in configuration produced a significant inhibition, $F(1,22) = 14.92$, $P < 0.0008$, that did not interact significantly with prime duration, $F(3,66) = 1.83$, $P > 0.15$. The priming effect of the configuration did not vary significantly as a function of gap conditions, $F < 1$, and the effect of prime duration on the priming effect was the same for the two gap conditions, $F < 1$. The inhibition effect averaged 28 ms in the small gap condition, $F(1,11) = 13.32$, $P < 0.005$, and 22 ms in the large gap condition, $F(1,11) = 5.83$, $P < 0.05$, and significant inhibition was observed as early as 40 ms, $F(1,11) = 6.17$, $P < 0.05$, $F(1,11) = 5.59$, $P < 0.05$, for the small gap and large gap conditions, respectively.

Similarity in components produced no significant priming effect, $F < 1$, nor a significant interaction with prime duration $F < 1$. The interaction between the effect of priming and gap condition was also not significant, $F(1,22) = 1.28$, $P > 0.27$.

These results replicated those of Kimchi (1998, experiment 1, few-element condition): An early inhibition for the configuration similarity condition, and no significant priming effects for the component similarity condition. That is, dissimilarity in components outweighed similarity in configuration, and similarity in components was rebated by dissimilarity in configuration, suggesting an early representation of the components along with a weaker representation of the global configuration that seems to consolidate with time.

The results of experiment 3 rule out the possibility that the difference between the results of experiments 1 and 2 with the line configurations and those of Kimchi (1998, experiment 1, few-element condition) is due to a difference in salience of the components. Rather, the difference between the pattern of results in experiment 3 and that of experiments 1, and particularly of experiment 2 (in which the structure of the same/different

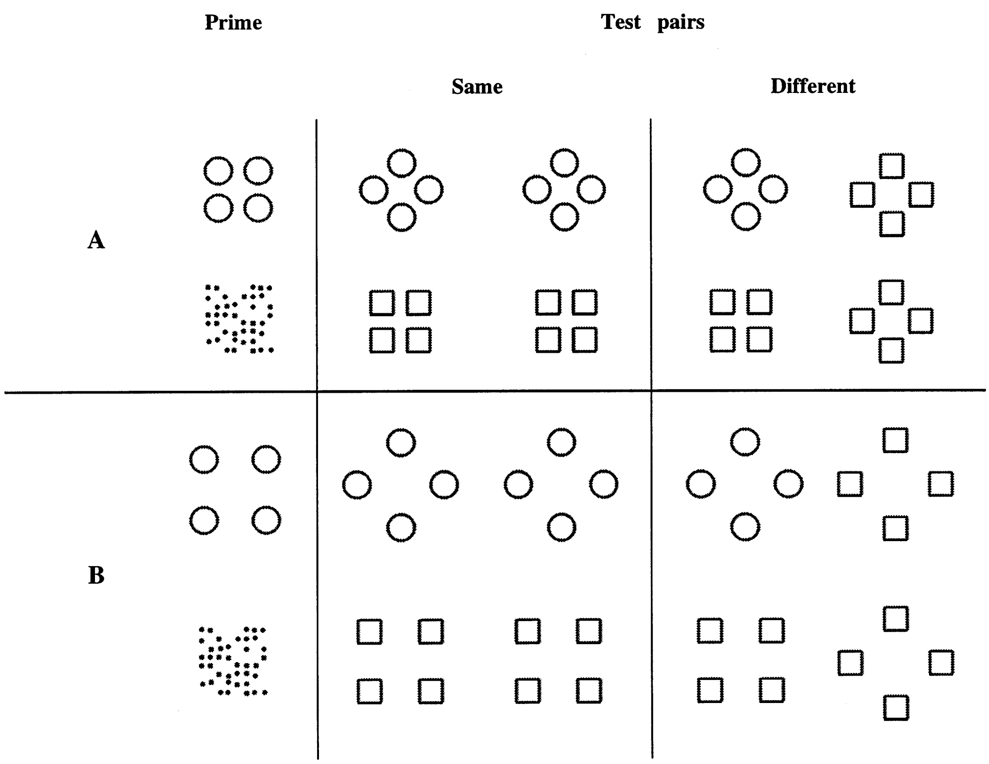

Fig. 6. The priming stimuli and the *same*- and *different*-response test pairs used in the (A) small gap condition, and (B) large gap condition, in experiment 3 (when the prime is a square configuration made of four circles and the test-pair is two squares made of four squares, prime-test similarity is *configuration similarity*; when the test-pair is two diamonds made of four circles then prime-test similarity is *component similarity*. When the prime is a random array of dots and the test-pair is either one, prime-test similarity is neutral, providing *configuration control* and *component control*, respectively).

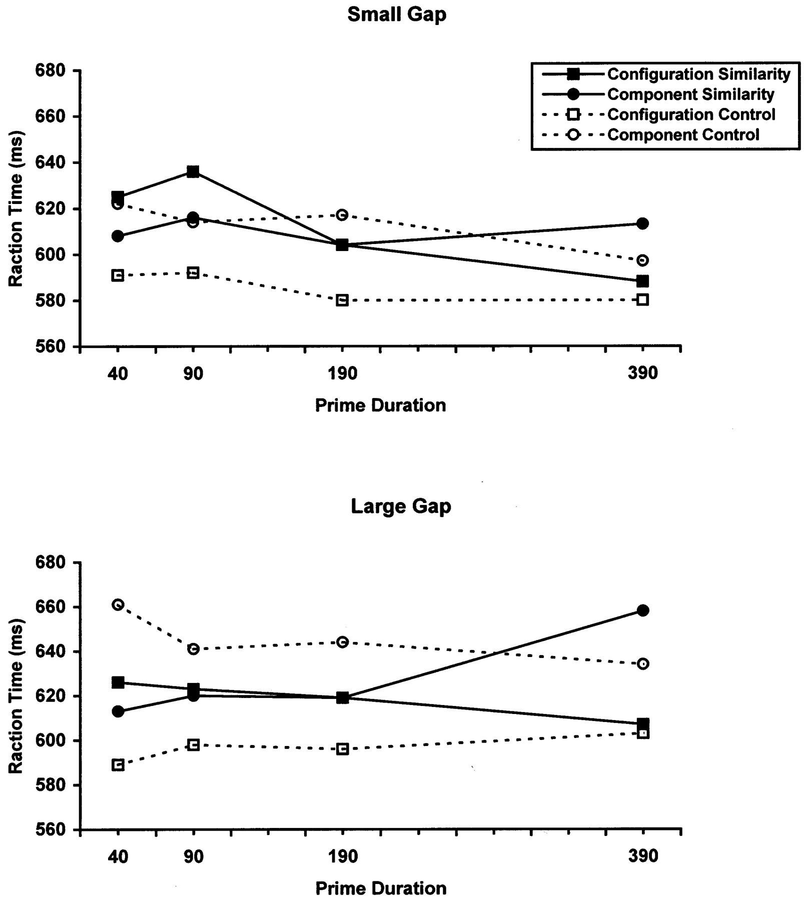

Fig. 7. Mean correct *same* RTs for the component similarity and configuration similarity test pairs as a function of prime duration in the prime and control conditions for each gap condition in experiment 3.

task was identical to that of experiment 3), suggests that the 'nature' of the components had an effect on the relative dominance of components and configuration. That is, an early relative dominance of components was found for stimuli composed of few closed shapes (i.e. the primes in experiment 3). On the other hand, an early relative dominance of configuration was found for stimuli composed of a few disconnected line segments (i.e. the primes in experiments 1 and 2).

5. General discussion

This study attempted to examine the microgenesis of the perceptual organization of visual configurations, and the role of UC in the early organization. The principle of UC (Palmer & Rock, 1994) states that connected regions of uniform visual properties correspond to the entry-level units of visual stimuli. The theory predicts that when a configuration is composed of components that are spatially separated from each other (as are the line segments in the primes of experiments 1 (gap conditions) and 2 or the outline circles in the primes of experiment 3), the components would be designated as entry-level units by virtue of UC. The results for the disconnected line configurations (experiments 1 and 2) showed that the configural organization of the disconnected line segments was available as early as the configuration of the connected line segments, and its effect outweighed possible effects of the lines. An early relative dominance of the components was observed only for the stimuli whose components were closed shapes (experiment 3).

These findings suggest that UC as applied to image-based properties is neither necessary nor sufficient for the designation of entry-level units (see also Peterson, 1994b; Kimchi, 1998; Han, Humphreys & Chen, 1999a). Rather, closure and collinearity seem to have as important a role if not more important in the early organization of visual stimuli.

The present results also provided information about the relationship between the grouping factors of closure, collinearity, and proximity. The Gestaltists failed to specify how different grouping principles are integrated, and since these principles have been proposed only a few studies examined this issue. The results of these studies seem to converge on the notion that proximity dominates similarity of shapes at early perceptual grouping (Ben-Av & Sagi, 1995; Han et al., 1999a; Han, Humphreys & Chen, 1999b). The present results show that proximity can facilitate grouping by either closure or collinearity, but the combination of closure and collinearity dominates proximity at early perceptual grouping, and least for the proximity range employed in the present experiments.

Kimchi's (1998) findings provided converging evidence for the role of number of elements and their relative size in the early organization of hierarchical patterns, affecting the relative dominance of components and configuration. Many, relatively small elements were rapidly grouped into global configuration without focused attention, and the individuation of the elements occurred with time and involved focused at-tention. Few, relatively large elements, on the other hand, were initially individuated and then grouped into configuration with time and with the involvement of focused attention (see also Enns & Kingstone, 1995, for more evidence for the latter). Further evidence for the effect of number on grouping comes from findings that demonstrated that the speed of detecting an odd target in the background of otherwise homogeneous distractors can actually increase when the number of distractors increased (e.g. Bacon & Egeth, 1991; Bravo & Nakayama, 1992), suggesting that the greater is the number of items, the better is the grouping.

The present results, however, suggest that the 'nature' of the components (open-ended line segments versus closed shapes) interacts with number and relative size. When the few, relatively large components were open-ended line segments, their configural organization was available very early provided the presence of collinearity and/or closure. On the other hand, when the few components were closed shapes, the components, rather than the configuration dominated the early organization of these figures.

Although there is no direct evidence concerning the effect of the 'nature' of the elements on early organization when the number of the element is rather large, it has been demonstrated that the perceptual advantage of the global level of many-element hierarchical stimuli depends on the type of properties involved. Kimchi (1994) found global advantage when classification was based on line orientation, but no global advantage was observed when classification was based on discrimination between closed versus open figures. Han et al. (1999b) used different stimuli and measured interference effects as well as overall RTs, and they did find global advantage for closure discrimination, but it was much weaker than the global advantage for orientation discrimination. Thus, both Kimchi's (1994) and Han et al.'s (1999b) results indicate that relative global or global advantage for many-element patterns depends on the properties involved at the local level. These findings are seen to suggest a competition between the individuation of the local elements and their grouping into global configuration, the result of which depends in part on the properties of the elements.

A possible explanation of the early priming effect of the configuration for the disconnected line segments (experiments 1 and 2) is that it might be due to blurring by large-scale, low resolution filters operating at early visual processing (e.g. Ginsburg, 1986). If the effect is due to such blurring then the existence of small gaps between the line segments should not greatly affect the priming effect. This explanation, however, cannot account for the differential effect of proximity on priming, namely, that proximity had an effect when either closure or collinearity was present, but had no effect when both closure and collinearity were present in the priming stimulus. These findings suggest that early organization is unlikely to be due to simple spatial filtering. Rather, the early configural organization of disconnected line segments is likely to be the result of rapid 'grouping' processes that rely on the computation of closure and collinearity (e.g. Kellman & Shipley, 1991; Rensink & Enns, 1995) among other factors, probably with some latitude concerning proximity.

The present results also have implication for the widely held dichotomy between an early, preattentive stage of processing, and a late attentive stage. The preattentive stage is characterized by rapid processes that extract in parallel over space simple features of the two-dimensional image such as orientation and color, and registering them in independent spatiotopic maps. The attentive stage is thought to assemble these features into coherent descriptions that correspond to the external objects via serial and time-consuming processes (e.g. Treisman, 1986, 1991).

The finding of early configural representation of disconnected line segments poses a difficulty for this view because it suggests the presence of an explicit representation of the spatial relationships between simple features (e.g. oriented lines) in early vision. This finding converges with other reports suggesting that the representations at the early levels are much more complex than suggested by the conventional view. Early levels have been found to be sensitive to complex, scene-based properties (e.g. Enns & Rensink, 1990; He & Nakayama, 1992; Kleffner & Ramachandran, 1992), to complete configurations rather than to components (Rensink & Enns, 1995), and to configural and to part-whole information (Kimchi, 1998). Early, rapid completion of occluded objects was also found (Shore & Enns, 1997; Rensink & Enns, 1998). These findings weaken the strict dichotomy between early preattentive versus late attentive processes.

Acknowledgements

This research was supported partly by a grant from the Israel Foundations Trustees (1996–1998), partly by a grant from the Ebelin and Gerd Bucerius – ZEIT – Foundation, and partly by the Max Wertheimer Minerva Center for Cognitive Processes and Human Performance, University of Haifa. It was conducted at the Institute of Information Processing and Decision Making, University of Haifa, and the article was prepared during my sabbatical with the Department of Psychology, Carnegie Mellon University. I am indebted to Yaffa Lev for programming the experiments, and to Irene Apfeld, Limor Lavie, and Michal Inzelbuch for running the experiments. I thank Marlene Behrmann and two anonymous reviewers for their comments.

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