Original Papers

Polish Psychological Bulletin
2015, vol. 46(4) 633–646
DOI - 10.1515/ppb-2015-0070

Piotr Styrkowiec[*]
Dominika Kras[**]

Forest before illusory trees: illusory contours of local level elements do not influence perceptual global advantage in the hierarchical structure processing

Abstract: *There is a continuing debate in the field of perceptual organization as to whether the locus of global processing is early or late perceptual, as previous studies have yielded contrary results. The conducted behavioural study explored this issue with the paradigm of collating global processing with other process of perceptual organization, namely illusory contours processing. Interaction between these two processes of perceptual organization would indicate that global processing has an early perceptual locus, whereas the lack of such interaction would suggest the late perceptual locus of global processing. In experiment 1, the effect of global dominance was obtained with the use of a compound figure composed of geometrical shapes with real edges. Results showed that the processing of the figure at the global level was faster and that it disrupted the processing of the figures from the local level. In experiment 1b, the compound figure was composed of local geometrical shapes generated with the use of the line-end induced illusory contours (Ehrenstein illusion). Local elements with illusory contours did not affect the processing of the hierarchical structure and the effect of global precedence occurred without any changes. In experiment 2a, a global advantaged effect within a compound figure with local elements with real edges was obtained in the paradigm of attention divided between levels of the hierarchical structure. When illusory contours of local elements of a compound figure were introduced to this paradigm (experiment 2b), this again had no effect on the perceptual global advantage. The results demonstrate the lack of interaction between global processing and illusory contour processing, indicating that the locus of global processing is rather late perceptual.*

Key words: *perceptual organization, global and local processing, illusory contours, locus of perceptual global advantage*

Introduction

Perceptual global processing refers to the organization of visual information that is dependent on the hierarchical structure of the stimuli. Navon (1977) presented the subjects' compound figure; a global letter composed of small, local letters. The global and local letters could be compatible or incompatible with each other. Navon found that reaction times to the global level were faster than to the local level and this was termed *global advantage*. Additionally, the global letter interfered with responses to the local letter when they were incompatible; the reverse was not observed and this was called *global interference*. Navon proposed the idea of global precedence stating that the global level properties of a hierarchically arranged array are processed before its local level properties.

Since the publication of Navon's original paper hierarchical structure processing has been extensively studied and theoretically analysed. Empirical studies focused mainly on defining the boundary conditions of the global advantage effect. This research allowed the identification of factors that can moderate or reverse the effect of global dominancy. For instance, global processing based on hierarchical perceptual organization may be modified by a change in the overall visual angle of the stimuli (Kinchla & Wolfe, 1979), the sparsity of local elements (Kimchi, 1988; LaGasse, 1993; Martin, 1979), location and spatial uncertainty of the stimuli (Grice, Canham & Boroughs, 1983; Lamb & Robertson, 1988), exposure duration (Luna, 1993; Paquet & Merikle, 1984), spatial frequency components contained in the compound stimuli (Badcock, Whitworth, Badcock & Lovegrove, 1990; Hughes, Nozawa & Kiterle, 1996; Lamb & Yund, 1996), luminance level (Hughes, Layton, Baird & Lester, 1984), factors that impede grouping or the recognisability of the global form (Enns & Kingstone, 1995; Hoffman, 1980),

[*] Institute of Psychology, University of Wroclaw, Poland, contact: piotr.styrkowiec@uwr.edu.pl
[**] Institute of Psychology, University of Wroclaw, Poland

and when the goodness of local forms are superior to that of the global form (Poirel, Pineau & Mellet, 2006; Sebrechts & Fragala, 1985). In addition, attention manipulation can modulate the effect (Kinchla, Macias & Hoffman, 1983; Lamb, Pond & Zahir, 2000; Robertson, 1996; Ward, 1982). Apart from identifying the boundary conditions of global advantage effect occurrence, the research also attempts to determine the neural basis of global advantage. Functional neuroimaging studies suggest hemispheric asymmetry with the right hemisphere biased toward global processing and the left hemisphere biased toward local processing (Fink, Halligan, Marshall, Firth, Frackowiak, Dolan, 1997; Kimchi & Merhav, 1991; Robertson, Lamb & Zaidel, 1993; Weissman & Woldorff, 2005). There is a continuing debate as to what is the source of this asymmetry, as it can be assigned to spatial frequency processing (Robertson & Ivry, 2000), sensitivity to the saliency of the stimulus (Mevorach, Humphreys & Shalev, 2006) or to the processes of information integration (Hubner & Volberg, 2005).

On theoretical grounds, global perceptual processing of the hierarchical structure is related to the concepts of global precedence and holistic primacy (Kimchi, in press). The former one states that the global configuration of a multi element pattern is represented before the individuation of the local elements. The latter one states that holistic properties dominate component properties in information processing. Both these accounts emphasize the configural and organizational aspects of this perceptual processing. It is stressed that global advantage is not an advantage of the global property of a visual object over local elements, but it is an advantage of higher level units' properties over the properties of lower level units (Kimchi, 1992). These holistic properties result from interrelations between the component properties of the stimulus (Kimchi, in press).

The referenced publications demonstrate that the field of research on global-local perceptual processing is very dense, especially in its empirical aspect. However, there are issues that are still unsettled. One such debated issue relates to the idea of the locus of perceptual global processing. There are two main viewpoints in this discussion, with one attributing the source of the global advantage to early perceptual processes and the other one claiming that the source can be found in late (or even post-) perceptual processes.

Navon claimed that global dominance arises early during sensory processing (Navon, 1977, 1981). It has been proposed that these sensory processes relate to the faster processing of low spatial frequencies than high spatial frequencies (Badcock, Whitworth, Badcock, & Lovegrove, 1990; Hughes, Fendrich, & Reuter-Lorenz, 1990; Shulman, Sullivan, Gish, & Sakoda, 1986). Some authors argued that global dominance is an effect of attention focusing that follows sensory processing (Palmer, Tzeng, & He, 1994; Ward, 1982). This claim was undermined by Paquet and Merikle (1988) who demonstrated that global dominance was obtained for objects located outside the focus of attention, which supports the concept of the perceptual locus of global advantage. It is a fact, however, that attention can modulate the effect of global dominance (Kinchla et al., 1983; Lamb et al., 2000; Robertson, 1996).

There is also other evidence for the perceptual locus of global dominance. Hughes, Layton, Baird & Lester (1984) showed that the magnitude of global precedence is related to the pattern luminance and, according to these authors, this demonstrates that the locus of global advantage can be assigned to early perceptual processing. In addition, studies that employ measures of the brain's electrophysiological responses demonstrate that the particular components of event related potentials (ERP) which reflect early sensory processing differ for global and local forms (Han, Fan, Chen, Zhuo, 1997; Han, Liu, Yund, Woods, 2000). This in turn supports the concept that hierarchical structure processing and global advantage are early perceptual processes. Miller and Navon (2002) conducted a study utilizing the Go/No-Go paradigm with the use of lateralized readiness potentials (a type of ERPs). Lateralized readiness potentials (LRP) are related to the increase of electrical activity at the brain's surface that reflects the preparation of motor activity on a certain side of the body. In the Go/No-Go paradigm, in the Go condition participants are required to respond with their right or left hand to a specific feature of the displayed object, such as the global or local shape. In some cases, subjects have to withhold their responses (No-Go condition). The analysis of the LRPs from the Go and No-Go conditions allow for the determination of the order of information processing. LRPs from the No-Go condition show what features drive hand selection before processing information that indicates a withholding of the response. With this method, Miller and Navon demonstrated that information from the global level is available to response activation before information from the local level. The authors presented the reasoning that the global shape recognition that precedes local shape recognition must take place before shape and response association. Thus, they concluded that global precedence is rather a perceptually based process.

Han and Humphreys (1999) used a compound figure in which global arrows or triangles composed of local arrows or triangles embedded in background crosses. The participants' task was to respond to global or local stimuli in terms of orientation or closure. Increasing the contrast of the background crosses led to a transition from grouping by proximity to grouping by similarity of shape. This, in turn, resulted in the elimination of the global precedence effect and the emergence of a local precedence effect. According to the authors, this demonstrates interaction between perceptual organization based on Gestalt laws and these are based on hierarchical processing. If hierarchical processing interacts with processes of perceptual organization, its locus is then perceptual.

Bruyer, Scailquin and Samson (2003) conducted a study on global precedence in which they recruited late perceptual processes. This was achieved in the following manner: the subjects' task was to recognize a compound letter either on the global or local level. The case of the letters varied, so the participants had to activate graphemic codes to makes their decisions. The global precedence effect was preserved, which, according to the authors, demonstrates that this effect originates early in perceptual processes and is then transformed to later stages of processing.

Koivisto and Revonsuo (2004) tested, with the use of masked priming, whether the global or local level of hierarchical patterns is analysed at the preconscious processing stages. In this study, participants were firstly presented very briefly with the prime stimulus (a compound letter) that was followed by the mask. Next, the target stimulus appeared, also a compound letter. The target letter could be either the same as the global letter of the prime or the same as the local letter of the prime. Only the global prime letters caused the facilitation of the target letters' identification. According to the authors, this demonstrates that the priority for global processing occurs at the preconscious level which, in turn, suggests that global advantage has a perceptual locus.

Andres and Fernandes (2006) manipulated the availability of post-perceptual processes for hierarchical structure processing by limiting the exposure duration of the compound stimuli. Global advantage occurred regardless of the exposure's duration, which, according to the authors, suggests that global advantage does not require post-perceptual processes such as decision making, the processing time of which is longer than the perceptual encoding of the stimulus. The authors state that this demonstrates that global advantage exists at an early perceptual stage of processing.

Some investigators claim that global advantage arises in late perceptual or even post-perceptual processes. Miller (1981) asked his participants to search for the target letter at the global or local level of the compound figure. He demonstrated that local information becomes available to decision processes within the same time course as global information. Based on this finding, Miller suggests that processes of decision and response selection are those that operate in a global-to-local manner rather than those of property extraction and detection. Boer and Keuss (1982) analysed courses of the speed-accuracy trade-off functions from the task of global and local classification judgements with hierarchical structures. Their analyses indicate that initial global and local detection have similar time courses. Researchers argue that the absence of an initial global advantage supports the concept of the post-perceptual locus of this effect, probably somewhere between perception and response selection. Ward (1982) found some attentional effects in hierarchical structure processing. According to this author, comparable global and local information have a similar processing status during sensory analysis and that attentional mechanisms (a feature integration that is assumed to require focal attention) that follow sensory processing are responsible for global dominance occurrence. Lamb and Robertson (1988) performed an experiment in which participants identified target letters that occurred randomly at the global or local level in a divided attention task. The visual angle was manipulated. Local RT advantage was found for the larger visual angle, but the global interference effect was independent of the visual angle. Based on the findings, researchers suggested that the RT advantage and interference do not index a sequential order of global and local processing and that local and global information might be processed in parallel. This indicates that global advantage does not arise at the perceptual level, but the effect is enhanced in some later stages (for instance, during response selection). The idea that global and local information is processed in parallel was tested in a study using ERPs that aimed at assessing electrophysiological correlates of local/global processing (Heinze and Münte, 1993). Electrophysiological results of the study supports the view that global and local target perception might be mediated by separated brain systems operating, at least initially, in parallel.

As can be seen from the presented publications the issue of whether the locus of global advantage is early or late perceptual is far from being settled. New research is thus required. We conducted a study in which we planned to explore the debated issue of the locus of global advantage. We planned to do this in a manner similar to that employed by Han and Humphreys (1999). In particular, we wanted to juxtapose global processing with some other type of perceptual organization processing. The potential interaction between these processes would indicate that the locus of global advantage is perceptual, whereas the lack of such interaction would indicate that global advantage might arise at some later stages of perceptual processing. In order to test these predictions we decided to employ perceptual organization processing based on illusory contours.

Illusory contours are an example of visual illusions. They generate a perception of a delimited surface that occludes parts of the inducing elements. The borders of this surface are perceived, although they are physically absent in the image. There are two main types of illusory contours. The first one relates to the completion of existing contours across gaps (Schuman, 1900) and its classic example is the Kanizsa triangle (Kanizsa, 1974). The other type relates to the formation of an illusory contour along the line terminators with the Ehrenstein illusion as the example (Ehrenstein, 1941). The strength of perceived illusory contours depends on geometric factors (Salvano-Pardieu, 2000; Shipley & Kellman, 1992). However, recent electrophysiological studies show certain limitations to this idea, especially regarding the influence of spatial factors on this perceptual illusion (Altschuler, Molholm, Russo, Snyder, Brandwein, Blanco & Foxe, 2012). Whether line-induced illusory contours are based on the same mechanism as a Kanizsa-type illusion is a matter of a discussion (see Salvano-Pardieu, Wink, Taliercio, Manktelow & Meigen 2006). The main debate on illusory contours relates to the issue as to whether they are based on low-level or high-level processes. Line-induced illusory contours are said to be determined in the brain at the early stage of processing of visual information (see Spillmann & Ehrenstein, 2004), though there are studies suggesting that the perception of illusory contours cannot be completed without the involvement of more complex processes (Gillam & Nakayama, 2002). This ongoing debate, regarding which mechanisms are responsible for the perception of illusory contours, is summarized by research reviews that conclude the processes responsible for the perception of illusory contours integrate neurophysiological and cognitive mechanisms (see Murrey & Herrmann, 2013; Spillmann & Dresp, 1995). This implies that illusory contours are not generated solely in the early stages of perceptual processing, but also engage other processes. Nevertheless, the processing of illusory contours belongs to the group of processes that are responsible for perceptual organization. Its perceptual nature is thus apparent.

As mentioned above we designed experiments in which we wanted to see whether there is or is not interaction between global processing and illusory contours processing. In order to achieve this goal we put together in one task these two types of perceptual organization processes. This comprised the following; a compound figure was prepared in which local elements were illusory shapes with no real, physical boundaries. With such a peculiar hierarchical structure, global advantage was then probed. Although in the hierarchical structure local components logically exist prior to the configuration of which they are part, the concept of global processing indicates that global configuration is processed before local components (see Kimchi, in press). In other words, global configuration is *perceived* before local elements are *perceived*. In our hierarchical structure, (a global figure with local shapes with illusory contours), perceptual processes are 'artificially' directed to the local elements. This forced engagement of the perceptual processes into local elements is represented by the fact that, in our special hierarchical structure, local shapes must be extracted from the illusory contours. Local shapes must be thus perceptually processed in order to become components of the global configuration. If the global processing of the hierarchical structure has an early perceptual locus, there should be an interaction of this processing with the perception of illusory contours of local elements. This interaction should be manifested in the interference of illusory contours processing with global processing. However, if global processing has a late perceptual locus, the processing of local elements of illusory contours should not lead to such interference, thus there should be no interaction between these processes of perceptual organization.

To our knowledge, the issue of global processing and illusory contours has not been extensively studied to-date. Conci, Müller & Elliott (2007) and Conci, Töllner, Leszczyński & Müller (2011) conducted studies on global and local processing in Kanizsa-figure detection, however, the goal of their studies related to the time-course of the processes of perceptual organization. Here, global processing and illusory contour processing were employed in one task, in order to explore the issue of the locus of global advantage.

Experiment 1A

As mentioned before global advantage is dependent on different factors with many relating to the issue of the compound figure and its hierarchical structure (see Kimchi, 1992; Navon, 2003). Therefore, it is crucial to have a compound figure that will enhance global processing. We decided to employ one of the compound stimuli similar to that used by Han, Humphreys and Chan (1999) which is a global triangle composed of local triangles. What is important is that this particular stimulus shape allows for the implementation of illusory contours in the next step of the study. The aim of experiment 1A was to obtain a global advantage effect using a compound figure composed of local shapes with real, physical boundaries. This global advantage effect in a standard compound figure should serve as a baseline for global processing in a hierarchical structure with local elements, with illusory contours from the subsequent experiment.

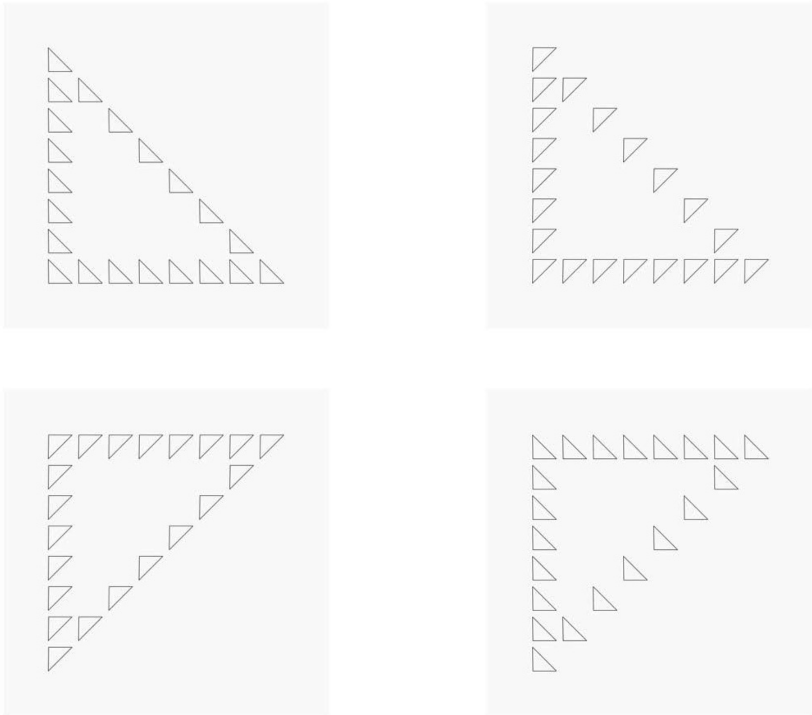
Method

Participants: thirteen students (six female, seven male) from the University of Wroclaw took part in the experiment as volunteers at the experimenter's request. Participants were aged from 18 to 31 years ($M = 24$, $SD = 4.08$). All had normal or corrected-to-normal vision and were unaware of the purpose of the experiment.

Apparatus and stimuli: participants were seated in front of a 19-inch LCD monitor (1280 x 1024 px resolution, 70 Hz refreshing rate) controlled by a standard personal computer (1.9 GHz, 8 GB RAM, AMD Radeon 7570 graphic card). The distance between the eyes and the screen was approximately 60 cm. Stimuli presentation and data collection were controlled by the Inquisit software system. The experiment took place in a sound-attenuated and darkened room. Reaction times (RTs) were recorded based on the responses given by pressing the appropriate buttons of two Saitek Aviator joysticks. Both joysticks were located on the desk so that each participant could comfortably lay both forearms on the desk while placing both hands on the joysticks' bases. The middle buttons at the front of each joystick base were used; participants pressed the button on the left joystick base with their left thumbs, and the button on the right joystick base with their right thumbs. The distance between the two joysticks positioned on both sides of the screen was approximately 50 cm.

Stimuli used in the experiment comprised compound figures structured in the following manner: a large right-angled triangle (global level) composed of 21 small right-angled triangles (local level) as illustrated in Figure 1. The vertical and horizontal legs of the small triangles were 32 pixels long (about 0.9 degree of a visual angle). Each small triangle had a thin black edge (1 px) made of a solid line and did not have any colour or pattern within. Spacing between the centres of two adjacent small triangles located on the horizontal or vertical leg of the large triangle was 40 pixels (about 1.1 degrees of a visual angle). Eight small triangles were aligned on each side of the large triangle creating its imaginary edges. The vertical and horizontal legs of the large triangle were 312 pixels long (about 8.7 degrees of a visual angle). The large triangle was presented on a light grey square (RGB values: 250, 250, 250) with each side 432 pixels long (about 12.2 degrees of a visual angle). The entire image was presented on a white background in the centre of the screen. Global and

Figure 1. Stimuli used in Experiment 1A and 2A. Left column: compound figures with congruence between levels. Right column: compound figures with incongruence between levels



local triangles appeared in one of two possible orientations: one, where the triangles' right angles pointed to the bottom-left corner of the screen and the other one where the triangles' right angles pointed to the top-left corner of the screen. Thus each orientation consequently determined the orientation of each triangle's diagonal, which could be either leftward (\) or rightward (/) respectively. If orientations of the global and local triangles were the same, there was a congruency between levels (congruent condition); if there was a mismatch of orientations between global and local triangles this was an incongruent condition. In sum, there were four types of compound figures with two congruent hierarchical structures and two incongruent ones.

Procedure: each trial began with the presentation of a white screen (500 ms). Then one of the four types of stimuli was presented (750 ms). After that, the white screen was presented again, either for 2,000 ms or until the participant responded to the stimulus. If there was no response a feedback screen informing the participant about the lack of a response was presented for 1,000 ms. Following the response or the feedback message there was a 1,750 ms pretrial pause, after which a new trial started. Participants were asked to respond as fast and as accurately as possible. RTs were measured from the stimulus onset. The participants' task was to indicate by pressing either the left or the right button with respectively the left or the right thumb whether the diagonal of the triangle at a particular level (global or local) was oriented leftward or rightward. There were two orientations assigned to the buttons (leftward orientation – left button, rightward orientation – right button and the reverse) and two levels to focus on – large triangle (global level) or small triangles (local level). The combination of these two factors gave four blocks that constituted the experiment. Each block consisted of 128 trials presented in random order. Each stimulus type was presented an equal number of times so the number of congruent and incongruent trials was the same. The order in which the blocks were presented in the experiment was randomized across participants. Before each block, the participants were explicitly informed about the types of orientation-response assignments. At the beginning of the experiment, participants were carefully instructed as to how to proceed with the task and were given a short practice session.

Results

All statistical analyses were conducted using IBM SPSS software. In order to correct for violations of the sphericity assumption in all ANOVAs, the Greenhouse-Geisser correction was used. Mean RTs for correct responses were subjected to two-way repeated measures analysis of variance (ANOVA) with the independent variables of the level on which participants focused their attention (with two levels: global and local) and congruency between diagonal orientation on both levels (congruent vs. incongruent). ANOVA revealed the main effect of level, $F(1, 12) = 41.09$, $p < .001$; with faster RTs when participants had to determine the orientation of the diagonal at the global level (509 ms) as compared to the condition of focusing on the local level (625 ms). There was also the main effect of congruency, $F(1, 12) = 74.63$, $p < .001$; participants responded faster when there was a ongruency of diagonal orientations between levels (549 ms) compared to the condition of no such congruency (585 ms). The interaction between the variables of level and congruency was significant, $F(1, 12) = 8.24$, $p = .014$ (see Figure 2). Participants were faster when responding to the global level than to the local one and when participants were focusing on the global level the difference between response rates in congruent (499 ms) and incongruent (520 ms) condition was insignificant as the post-hoc comparison revealed (Scheffé test, p=.05). However, for reaction times at the local level the congruency of diagonal orientation differentiated results (post-hoc Scheffé test, p=.05). In the case of responding to local triangles when there was an incongruence of diagonal orientation between levels, response times were much longer (650 ms) as compared to the congruent condition (599 ms).

The analysis of the accuracy of the results showed only the main effect of congruency, $F(1, 12) = 6.76$, $p = .023$. Participants gave more correct answers in the congruent condition (93.5%) than in the incongruent one (87.5%).

Discussion

Experiment 1A showed a robust global advantage effect in visual perception, although only for reaction time measures. The task was performed in a condition of divided attention, in which, while concentrating on one level the other one was ignored. Hierarchical perceptual processing of the compound figure from experiment 1A resulted in global precedence and global interference (see Navon 1977). The former relates to the fact that objects at the global level, which are composed of local level objects, are processed faster than those objects from the local level. It could be thus inferred that object representations of the global objects are available for processing before the objects' representation from the local level. The former refers to the fact that, when focusing on the local level, incongruent information from the global level delays the overall reaction times. No such effect was observed for the opposite condition, where incongruent information from the local level was available while focusing on the global level. The interpretation of this observation is that information from the global level interferes with the processing of information from the local level. Experiment 1A confirmed that the utilized task and stimuli constitute good tools for eliciting the global advantage effect in hierarchical structure processing.

Experiment 1B

In this experiment, illusory contours were introduced in order to engage perceptual processes to local elements of the compound figure. Solid lines marking the boundaries of local elements were removed. The edges of local elements were now determined by line-ends inducers. The local shapes of the compound figure were generated with the use of the Ehrenstein-like illusion. A set of thin lines surrounded empty spaces and formed the shape of triangles. Induced triangles had no real, physical boundaries; their edges were determined by line-ends (see Figure 3). To balance the figure-ground organization a reversed Ehrenstein illusion was used. In this case, thin lines served as the texture of triangle-shaped surfaces. Again, the shapes had no real physical boundaries in the form of solid lines as their edges were induced by the ends of lines. In the case of the Ehrenstein type illusion, inducing lines formed a background for the illusory shape. It has been shown that the contrast of the background for the compound

Figure 2. Mean reaction times (RT) to global and local levels of compound figure in congruent and incongruent condition from Experiment 1A

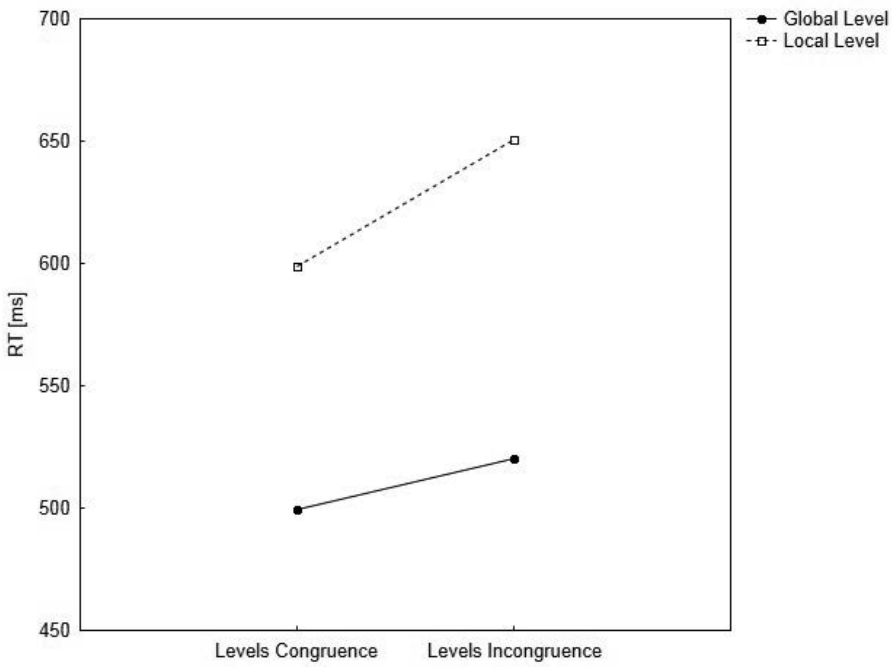


figure influences hierarchical structure processing (Han et al. 1999; Han & Humphreys, 1999), which is why we employed the reverse of the Ehrenstein illusion in order to control the factor of background contrast. This experiment was designed to test whether global processing is influenced by the perceptual processing of illusory contours in the local elements. The main objective was to test if global processing is changed in such conditions. If the effect of global processing undergoes modification in this setting, this indicates that the processing of illusory contours interacts with global processing and that the locus of the latter is perceptual. If there is no change to global processing, that is no interaction with illusory contours processing, this in turn implies that the locus of global processing is late perceptual.

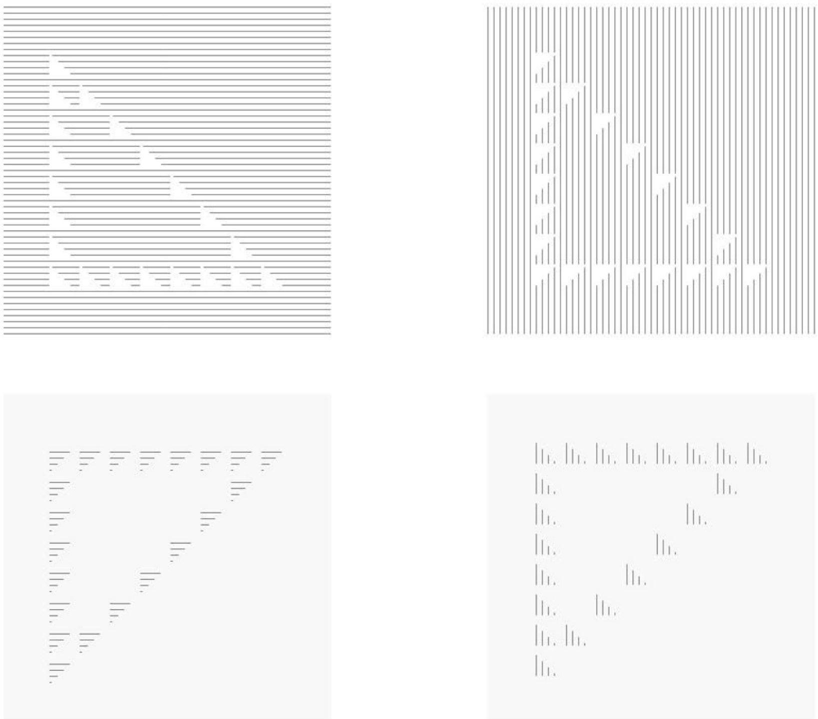
Method

Participants: thirteen students (seven female, six male) from the same population as in experiment 1A volunteered to take part in the experiment. None of the volunteers had participated in the previous experiment. Their age ranged from 21 to 36 years ($M = 24.46$, $SD = 4.35$). All had normal or corrected-to-normal vision.

Apparatus and stimuli: experiment 1B was carried out in the same experimental setup as experiment 1A, with the following modifications that relate to the stimuli. A compound figure with Ehrenstein type illusory contours of local elements was obtained in the following manner. The light grey square from the previous experiment was replaced by grating made up of thin solid lines. Each line was one pixel wide and 432 pixels long (about 12.2 degrees of a visual angle). The entire grating was located in the centre of the screen on a white background. The spacing between the lines was 8 pixels (about .2 degrees of a visual angle). The lines in the grating could be in the vertical or horizontal position. Local triangles of which the large triangle was comprised were superimposed on the grating. Each local triangle had a white filling (the same colour as the background) and their edges were removed. This created 'empty' spaces in the places where the small triangles normally would be seen (see Figure 3). The compound figure with the reversed Ehrenstein illusion was constructed as follows; the light grey rectangle, the same as in experiment 1A remained as the background. Each local triangle was filled with a pattern of four thin vertical or horizontal lines of different length. The spacing between the lines was of 8 pixels. The edges of the local triangles (thin solid lines) were removed (Figure 3). Four stimuli types previously used in experiment 1A could thus be now of two types: either the Ehrenstein illusion or the reversed Ehrenstein illusion. Since the thin lines could be in the vertical or the horizontal position, there were 16 stimuli types in total.

Procedure: the stimuli were presented in the same fashion as in the previous experiment and the course of each trial was the same as in the first experiment. Similarly,

Figure 3. Example stimuli used in experiment 1B and 2B. Left column: compound figures with congruence between levels. Right column: compound figures with incongruence between levels. Top row: local elements generated with Ehrenstein type illusion. Bottom row: local elements generated with negative of Ehrenstein type illusion



the task for each participant was also the same. The only modification related to the blocks. In this experiment, there were eight blocks, each with 176 trials. In half of the blocks Ehrenstein illusion type stimuli were presented, in the other half the stimuli with the reversed Ehrenstein illusion were used. In half of the trials the participant focused on the global level of the compound figure, in the other half on the local level. Finally, in half of the blocks the left button press was assigned to the leftward orientation of the diagonal at a particular level and the right button press to the rightward orientation of the diagonal. In the other half of the blocks the response to target stimulus assignment was reversed. The order of blocks was randomized across participants. In all other respects, this experiment was identical to the previous one.

Results

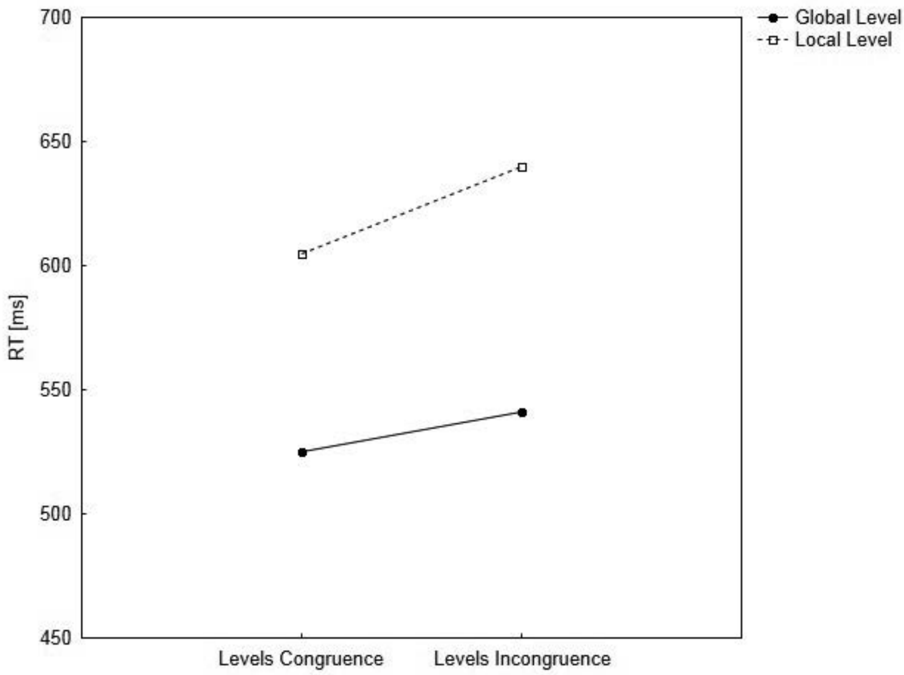
Mean RTs for correct responses were subjected to three-way repeated measures ANOVA with the independent variables of the level at which the participant focused their attention (global or local), the congruency of diagonal orientations between the level (congruent or incongruent) and the type of local elements' illusory contours (the Ehrenstein illusion type or the reversed Ehrenstein illusion). ANOVA revealed the main effect of the level, $F(1, 12) = 62.42$, $p < .001$; with faster RTs when participants were asked to determine the orientation of the diagonal at the global level (533 ms) as compared to the condition where they were asked to focus on the local level (622 ms). There was also the main effect of congruency, $F(1, 12) = 24.47$, $p < .001$; participants responded faster when there was congruency of diagonal orientations between levels (565 ms) as compared to the condition of no such congruency (590 ms). The main effect of the type of illusory contours was also significant $F(1, 12) = 21.99$, $p < .01$; participants responded faster to stimuli with the reversed Ehrenstein illusion (565 ms) than to stimuli with Ehrenstein type illusory contours (591 ms). In addition, the interaction between the level and congruence $F(1, 12) = 7.88$, $p < .05$, (Figure 4) was significant. Participants were faster when responding to the global level than to the local. When focusing on the global level, the difference between response rates in congruent (525 ms) and incongruent (541 ms) conditions was insignificant as the post-hoc comparison showed (Scheffé test, $p = .05$). For reaction times at the local level, however, the congruency of diagonal orientation had differentiated results (post-hoc Scheffé test, p=.05). When responding to local triangles when there was an incongruence of diagonal orientation between levels, response times were much longer (640 ms) as compared to the congruent condition (605 ms). All other interactions were insignificant.

ANOVA of accuracy measures revealed two main effects. One was the main effect of the variable level, $F(1, 12) = 7.3$, $p < .05$; participants responded more correctly when focusing on the global level (94%) rather than on the local level (89%). The second main effect was of the congruency variable $F(1, 12) = 7.7$, $p < .05$; with more correct responses in the congruent condition (93%) than in the incongruent one (89%). The other main effect and interactions were insignificant.

Mixed ANOVA

Mixed-design ANOVA was performed on data obtained from experiments 1A and 1B. ANOVA was performed with real or illusory contours of local elements as a between

Figure 4. Mean reaction times (RT) to global and local levels of compound figure in congruent and incongruent condition from Experiment 1B



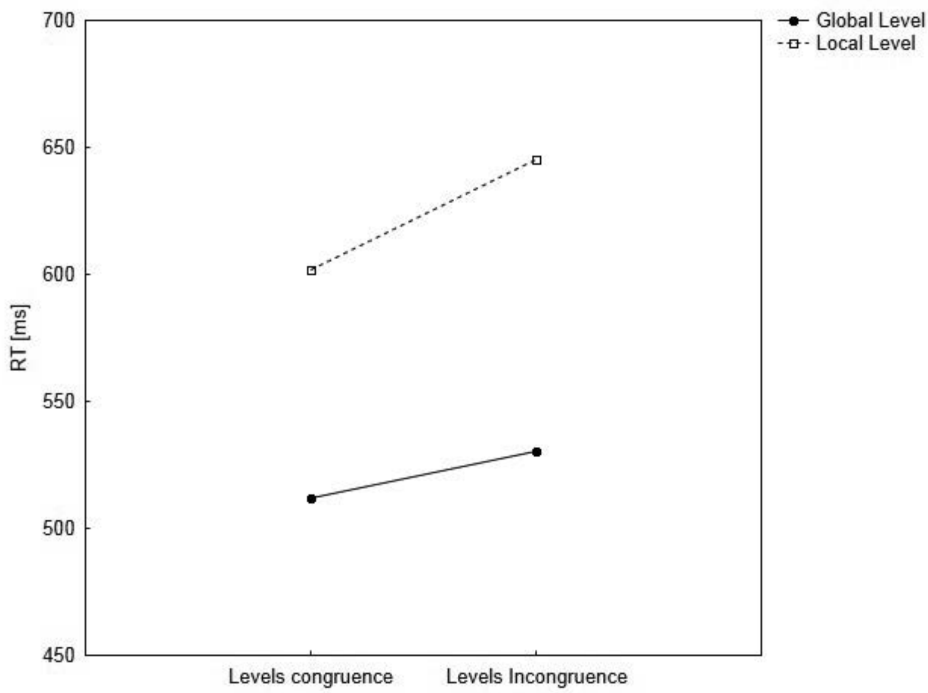
groups factor and the level at which participants focused their attention and congruency of diagonal orientation between levels as within groups factors. For RTs measures the main effect of the contour type was not significant (p = .737); mean RT in experiment 1A was 567 ms and in experiment 1B it was 577 ms. Also the interaction of the level by the type of contour (p=.24), the interaction of congruency by the type of contour (p=.11) and the three-way interaction between the level, the congruency and the type of contour was insignificant (p=.38). The main effect of the level was significant $F(1, 24) = 95.1$, $p < .001$; as was the main effect of the congruency $F(1, 24) = 88.16$, $p < .001$. The interaction between the level and the congruency was also significant $F(1, 24) = 15.2$, $p < .01$, and the pattern of this result showed the global advantage effect as can be seen in Figure 5. For accuracy measures mixed ANOVA revealed the main effect of the level $F(1, 24) = 6.46$, $p < .05$. In addition, the interaction of the congruency by the type of contour was significant $F(1, 24) = 13.05$, $p < .01$. This interaction showed that in the congruent condition participants gave more responses that are correct in reaction to illusory contours compared to the real edges. This was reversed for the incongruent condition. In this case, more responses that were correct were obtained for real rather than for illusory contours. Other main effects and interactions were insignificant.

Discussion

Experiment 1B showed that global advantage occurred in a compound figure composed of local elements with illusory contours. Importantly, two aspects of perceptual global advantage namely global precedence and global interference were both present. The processing of the global form preceded the processing of the local forms and information from the global level disturbed the processing of information from the local level. This global advantage occurred in a hierarchical structure where local objects had no real physical boundaries. Objects with illusory contours were grouped to form a global object in the same way as local objects with real edges. This happened independently of the employed type of illusory contours. Although illusory contours elicited using the reversed Ehrenstein illusion were processed faster than illusory contours generated with the use of the Ehrenstein type illusion this had no effect on global advantage. This demonstrates that the processing of illusory contours does not interact with hierarchical structure processing, which was also confirmed by mixed ANOVA performed on data from experiments 1A and 1B. In both experiments global advantage occurred in the same shape and in a very similar size. The extraction of boundaries of elements with illusory contours is a processing of perceptual information from the local level. These processes did not influence the difference in the speed of the processing between the global and the local level and did not affect the size of interference of global information at the local level. This result demonstrates that illusory contours processing and global processing do not interact. According to the rationale that underpins this study, the lack of interaction between the two types of perceptual organization processes in this particular setting of hierarchical structure processing indicates that global advantage has its locus in late perceptual processes.

Processes of perceptual organization are interrelated with mechanisms of visual attention (see Kimchi & Razpurker-Apfeld, 2004). Perceptual hierarchical

Figure 5. Interaction between level consistency and level to which participant responded as revealed by the mixed ANOVA of results from Experiment 1A and 1B



processing of a compound figure is no exception. Moreover, as Navon (2003) pointed out, eliciting global processing is sensitive to attention engagement and postulates that a better method for a testing mechanism of global advantage is the employment of a compound figure in a task with a divided attention condition than the use of a focused attention paradigm. A divided attention condition allows for the enhancement of perceptual mechanisms that are responsible for evoking global processing. Additionally, the divided attention setting helps to obtain a condition which is *perceptually purer* and is not confounded by attentional factors that result from focused attention. The lack of interaction between the processes of perceptual organization that was observed in experiment 1B might be a consequence of focused attention on a particular level of the compound figure. It is thus worth testing if illusory contours processing interferes with global processing in the purer perceptual condition of hierarchical structure processing, namely in a condition of divided attention. Subsequent experiments were undertaken to test this theory.

Experiment 2A

Unlike the method used in the first two experiments, where participants were asked to focus their attention on a particular level while ignoring the other one, here we introduced a divided attention condition where both levels were equally important. This was achieved by the employment of a task in which a participant was required to search for a target that could be localized on the local level or on the global level or on both levels. In the case of such a visual search, attention is equally distributed across both levels of the compound figure. In the following experiment, we tested how the experimental setup with a divided attention task on a compound figure with local elements with real physical edges allows for obtaining the global advantage effect. Similar to experiment 1A, this experiment was set as a baseline for global processing in a hierarchical structure with local elements with illusory contours from the next experiment.

Method

Participants: thirteen students (seven female, six male) from the same population as in the previous experiments took part in the experiment as volunteers. None of the volunteers participated in the previous experiments. Their age ranged from 19 to 27 years ($M = 21.77$, $SD = 2.01$). All had normal or corrected-to-normal vision and were unaware of the purpose of the experiment.

Apparatus and stimuli: experiment 2A was carried out in the same experimental setup as experiment 1A, with the same stimuli – large triangles made up of small triangles with real physical edges. The main modification included the procedure and participants' task.

Procedure: each trial began with the presentation of a white screen (500 ms). Then a diagonal black dashed line (175 pixels long; around 5 degrees of a visual angle) was presented in the centre of the screen on a light grey square for 750 ms. The diagonal line could be oriented leftward (\) or rightward (/) and determined the target orientation. After that, the mask was presented for 750 ms in a centre. The mask was a square grating consisting of nine thin, black, solid lines that were vertical in orientation and nine horizontal lines. The grating was of 122 x 122 pixels in size (around 3.5 x 3.5 degrees of visual angle). Then one of the four types of a compound figure from experiment 1A was presented for 750 ms. Following that, a white screen was presented again, either for 2,000 ms or until the participant responded to the stimulus by pressing a button. If there was no response, the feedback screen was presented for 1,000 ms, informing the participant that she or he had not responded. After the response or the feedback message there was a pre-trial pause that lasted for 1,750 ms and a new trial started. The participants' task was to indicate by pressing the left or the right button with the left or the right thumb respectively, depending on whether the particular orientation of a diagonal, as indicated at the beginning of each trial, was present somewhere in the compound figure. The task was to decide whether the diagonals of local triangles, the global triangle or both were oriented in the same way as the initial diagonal line. Participants were required to answer 'yes' if a target orientation was present either on the local level or the global level or on both levels. If the primed target orientation was not present in either the local and global triangles participants were required to answer 'no'. Participants were asked to respond as fast and as accurately as possible. RTs were measured from the stimulus onset. Each orientation of an initial diagonal line preceded each type of compound figure an equal number of times. There were two blocks with 144 trials each. A trial was presented in random order within every block. In one block the 'yes' answer was assigned to the left button press and the 'no' answer to the right button, in the other block it was reversed. Blocks were run in random order for each participant.

Results

RT analysis: in the first step a one-way within-subjects ANOVA was performed with a variable of congruence of diagonal orientation between levels (congruent vs. incongruent). In the congruent condition, this is when the global triangle had a diagonal with the same orientation as the local triangles, participant could give the 'yes' or 'no' answer due to the task requirements. A 'yes' answer was expected if the target orientation determined by the prime from the beginning of the trial was present in the compound figure on both levels. If this target orientation was not present in the compound figure a 'no' answer was expected. In the incongruent condition, participants could answer only 'yes' and all these cases were taken into account for analysis.

In the congruent condition, participants could answer 'yes' or 'no' but only the cases with 'yes' answers were taken into account for analysis. Thus the cases with 'no' answers were rejected because they had no counterpart in the incongruent condition. The same type of decisions then had to be compared. Decisions associated with the presence of the primed target are different to those associated with its absence. One-way within-subjects ANOVA revealed the significant effect of congruence, $F(1, 12) = 76.83$, $p < .001$; participants were faster in their responses when there was a congruence within the compound figure (719 ms) as compared to the incongruent condition (962 ms).

In the next step, only data from the incongruent condition was analysed. One-way within-subject ANOVA was conducted with the variable of the level at which the primed diagonal orientation was present (global or local). The effect of the level was significant, $F(1, 12) = 27.86$, $p < .001$; responses were faster when the compound figure with incongruence between the levels contained the target diagonal orientation at the global level (857 ms) rather than at the local level (1072 ms).

The same analyses were performed for accuracy measures although both effects were not significant.

Discussion

Experiment 2A showed that the introduced task provided a good method for obtaining other than the usual indicators of the global advantage effect. Results indicate that when there is incongruence between the levels in the hierarchical structure, the processing of the global level overrides that of the local level. This confirms the prevalence of the global level in hierarchical structure processing. Additionally, this prevalence of perceptual global processing was demonstrated in a condition where attention was equally distributed over both levels, which, in consequence, provided better conditions for purer perceptual processes. In the next experiment, we tested whether in such conditions the processing of illusory contours of local elements has any effect on perceptual grouping based on global processing.

Experiment 2B

Method

Participants: thirteen students (seven female, six male) from the same population as in previous experiments took part in the experiment as volunteers. None of the volunteers participated in the previous experiments. Their age ranged from 22 to 34 years ($M = 25$, $SD = 3.32$). All had normal or corrected-to-normal vision and were unaware of the purpose of the experiment.

Apparatus and stimuli: experiment 2B was carried out in the same experimental setup as experiment 2A, the only modification related to the stimuli and the number of blocks. In experiment 2B eight stimuli from experiment 1B were used, i.e. compound figures with local elements with illusory contours. There were four blocks with 144 randomly ordered trials in each block. In half of the blocks, compound figures with the Ehrenstein type illusion were presented while in the other half stimuli with the reversed Ehrenstein illusion were presented. In half of the blocks, participants responded 'yes' with their left hand and 'no' with their right hand, in the other two blocks it was reversed. In all other respects, experiment 2B was the same as experiment 2A.

Results

RT analysis: similar to the previous experiment there were two steps of analysis. In the first one two-way within subjects ANOVA was performed with a variable type of local elements illusory contours (Ehrenstein illusion type or reversed Ehrenstein illusion) and congruence of diagonal orientation between levels (congruent vs. incongruent). Similar to the previous experiment in the congruent condition only the 'yes' answers were taken into account. This ANOVA revealed only the main effect of congruence, $F(1, 12) = 57.4$, $p < .001$; participants were faster in their responses when there was a congruence within the compound figure (693 ms) as compared to the incongruent condition (906 ms). The other main effect and the interaction between variables were insignificant.

In the second step, data only from the incongruent condition was analysed. Two-way within-subject ANOVA was conducted with the variable of the type of local elements illusory contours (Ehrenstein illusion type or reversed Ehrenstein illusion) and the level at which primed diagonal orientation was present (global or local). Only the main effect of the level was significant, $F(1, 12) = 6.73$, $p < .05$. Responses were faster when the compound figure with incongruence between the levels contained the target diagonal orientation at the global level (861 ms) than at the local level (959 ms).

Analysis of accuracy measures did not revealed any significant results.

Mixed ANOVA

Two mixed ANOVAs were performed on the data from the experiments 2A and 2B. The first ANOVA was run with either real or illusory contours of local elements as a between-groups factor and the congruence of diagonal orientation between levels as within-groups factors. ANOVA on the RT data indicated that the main effect of the type of the local elements' contour was not significant ($p = .41$); mean RT in the experiment 2A was 840 ms and in experiment 1B it was 798 ms. Also the interaction of the congruence by the type of contour was insignificant (p=.46). The main effect of congruence was significant $F(1, 24) = 132.3$, $p < .001$; mean RT in the congruent condition was 706 ms and in the incongruent condition it was 933 ms. For accuracy measures this mixed ANOVA revealed the significant main effect of congruence $F(1, 24) = 5.92$, $p < .05$ (mean correct responses in the congruent condition 93%, and mean correct responses in the incongruent condition 86%). The other main effect and the interaction were not significant.

The second ANOVA was performed with two factors: the type of local elements contour (real or illusory) as a between-groups factor and the level at which primed diagonal orientation was present (global or local) as within-groups factor. ANOVA on the RT data indicated the main effect of the level, $F(1, 24) = 35.26$, $p < .001$; RTs were faster when the primed diagonal was located at the global level (855 ms) than when it was at the local level (1015 ms). The main effect of the type of local elements contour was insignificant (p=.38; 964 ms real contours and 906 ms illusory contours). However, the interaction between these two factors came close to reaching statistical significance $F(1, 24) = 4.26$, $p = .05$. The difference in RTs between the condition when the primed diagonal was located at the global level and when it was located at the local level was greater for compound figures with local elements with real contours (215 ms) as compared to differences for the compound figure with local elements with illusory contours (104 ms). Although it seems that illusory contours affect global and local processing, because of the small effect size, this influence may be assumed to be marginal. For accuracy measures there were no significant results.

Discussion

Experiment 2B showed that the illusory contours of local elements of a compound figure do not affect the global advantage effect in a divided attention condition. In this condition attention is equally distributed between both levels of the hierarchical structure and the visual input from either level was not enhanced by the processes of visual attention to the disadvantage of the visual input from the other level. In such a case, perceptual mechanisms play a major role and the processing of the visual input is moderated by the attention mechanisms to a smaller extent. This purer perceptual condition however, did not lead to the interaction between illusory contours and hierarchical structure processing. In the condition of incongruence between the levels of the compound figure, the global element was processed faster than the local elements. When perceptual resources are equally engaged in processing at both levels and none of them is ignored (as in the task from experiments 1A and 1B), the processing of the global level tends to precede the processing of the local level. This demonstrates global advantage in visual perception. This global advantage is not influenced by the processing of illusory contours at the local level. Thus, in the condition when perceptual processes operate with limited influence from visual attention, or in other words appear in their 'purer form', the two perceptual organization processes do not interact with each other as the processing of illusory contours does not interfere with global processing. The lack of interaction between these processes of the perceptual organization in this particular hierarchical structure processing supports the idea that the locus of global processing is rather late perceptual.

General discussion

In the field of perceptual organization based on hierarchical structure processing there is a continuing discussion about the locus of global processing. There are two main viewpoints in this discussion, with one claiming that the locus of global processing is early perceptual and the other stating that this locus is late or even post-perceptual. Evidence in favour of each of these viewpoints can be found in publications. The current study is aimed at exploring this issue. To this end, we designed experiments in which perceptual global processing was probed in a setting where other perceptual organization processes, namely illusory contours processing, was engaged. We reasoned that if global processing has an early perceptual locus, employment of the other perceptual organization process should result in interaction between them. If, however, global processing has a late perceptual locus other perceptual organization process should not affect it and there should be no interaction between these two types of perceptual organization processes. We collated global processing and illusory contours processing in the following manner; hierarchical structure processing was probed with the use of a compound figure in which the local elements were shapes with illusory contours. Results showed that global advantage (faster and more accurate processing of the global rather than local shapes) and global to local interference occurred in the compound figure in the same manner, both when local elements of the hierarchical structure had real physical boundaries and when local elements were shapes with no real edges, but with line-induced illusory contours. In other words, global processing in the hierarchical structure is observed regardless of whether the local elements have real or illusory contours. The processing of local elements illusory contours does not interfere with the global processing of the compound figure. Thus, there is no interaction between these two processes of perceptual organization. Moreover, this lack of interaction between illusory contours and global advantage in the hierarchical structure was observed in two different experimental conditions. Firstly, one related to the classic Navon type task (Navon, 1977) where attention was focused on one level of the compound figure while the information from the other level was attenuated. In the other condition attention was divided between the levels of the hierarchical structure, which means that attentional resources were equally engaged in the processing of information from both levels and neither of them received more attentional enhancement than the other. Such a condition allowed for the occurrence of 'purer' perceptual processes as the attentional influence was restricted (Navon, 2003). It needs to be emphasised that the lack of interaction between two processes of perceptual organization occurred even in the pure perceptual setting, where perception played the main role and the influence of other cognitive functions was limited.

The obtained results provide support for the claim that global processing has a late perceptual locus. Two processes of perceptual organization, namely the processing of illusory contours and global processing, do not interact within hierarchical structure processing. In a compound figure composed of local elements with illusory contours, extraction of the local objects from illusory boundaries engaged the perceptual processes into the local level. Even though this did not lead to the interaction of these perceptual processes with those related to global processing. As the concept of global processing states, global configuration is perceived before local components. In case of our study, perception is 'artificially' directed to local components. However, this perceptual process does not influence perceptual global processing in this particular setting. This indicates that, in such conditions, global processing occurs after the perception of local elements. This in turn suggests that global advantage has its locus in late perceptual processing.

There is one factor that needs to be mentioned and emphasized at this point. Although the obtained results seem to demonstrate that the processing of illusory contours and global processing do not interact in the hierarchical structure processing of the compound figure with local elements with illusory contours, such interaction might be possible with a slightly different visual input. For example, as was mentioned in the introduction, different types of compound figures allow for local advantage in the hierarchical structure processing to occur (see Kimchi, 1992). In addition, the processing of line-induced illusory contours is sensitive to the features of the line-ends (see Lesher & Mingolla, 1994). It is thus possible that careful manipulation of spatial features of elements composing global configuration and those of lines that induce illusory contours might lead to such a condition in which interaction of these two kinds of perceptual organization processes can occur. Additionally, as Di Lollo and colleagues point out (Di Lollo, Kawahara, Zuvic, & Visser, 2001) that perceptual organization is a dynamic system of different processes that are flexibly adjusted and configured to optimally handle the task at hand. It is thus possible that the lack of interaction between the two processes of perceptual organization in the task employed in this study was a consequence of that perceptual organization adjustment to the requirements of the task. Perhaps with some other perceptual task these two processes of perceptual organization might interact with each other.

In summary, the article presents new results in the empirically dense domain of global-local processing – that global advantage of hierarchical patterns is observed regardless of whether the local elements have real or illusory contours. Two types of perceptual organization processes, namely global processing and illusory contours processing do not interact. This, in turn, provides evidence in favour of the claim that the locus of global processing is rather late perceptual.

References

Altschuler, T., Molholm, S., Russo, N., Snyder, A., Brandwein, A., Blanco, D., & Foxe, J. (2012). Early Electrophysiological indices of illusory contour processing within the lateral occipital complex are virtually impervious to large-scale manipulations of illusion strength. *NeuroImage*, *59*, 4074–85. doi: 10.1016/j.neuroimage.2011.10.051

Andres, A.J.D., & Fernandes, M.A. (2006). Effect of short and long exposure duration and dualtasking on a global-local task. *Acta Psychologica, 122*, 247–266. doi: 10.1016/j.actpsy.2005.12.002

Badcock, J.C., Whitworth, F.A., Badcock, D.R., & Lovegrove, W.J. (1990). Low-frequency filtering and the process of local–global stimuli. *Perception*, *19*, 617–629. doi: 10.1068/p190617

Boer, L.C., & Keuss, P.J.G. (1982). Global precedence as a postperceptual effect: An analysis of speed-accuracy tradeoff functions. *Perception & Psychophysics*, *13*, 358–366. doi: 10.3758/BF03202660

Bruyer, R., Scailquin, J.C., Samson, D. (2003). Aging and the locus of the global precedence effect: A short review and new empirical data. *Experimental Aging Research*, *29*, 237–268. doi: 10.1080/03610730303724

Conci, M., Müller, H.J., & Elliott, M.A. (2007). The contrasting impact of global and local object attributes on Kanizsa figure detection. *Perception & Psychophysics*, *69*, 1278–1294. doi: 10.3758/BF03192945

Conci, M., Töllner, T., Leszczyński, H.J., & Müller, H J. (2011). The time-course of global and local attentional guidance in Kanizsa-figure detection. *Neuropsychologia*, *49*, 2456–2464. doi: 10.1016/j.neuropsychologia.2011.04.023

Di Lollo, V., Kawahara, J., Zuvic, S.M., & Visser, T.A. W. (2001). The preattentive emperor has no clothes: A dynamic redressing. *Journal of Experimental Psychology: General*, *130*, 479–492. doi: 10.1037/0096-3445.130.3.479

Ehrenstein, W. (1941). Über Abwandlungen der L. Hermannschen Helligkeitserscheinung. *Zeitschrift für Psychologie*, *150*, 83–91.

Enns, J.T., & Kingstone, A. (1995). Access to global and local properties in visual search for compound stimuli. *Psychological Science*, *6*, 283–291. doi: 10.1111/j.1467-9280.1995.tb00512.x

Fink, G.R., Halligan, P.W., Marshall, J.C., Frith, C.D., Frackowiak, R.S.J., & Dolan, R.J. (1997). Neural mechanisms involved in the processing of global and local aspects of hierarchically organized visual stimuli. *Brain*, *120*, 1779–1791. doi: 10.1093/brain/120.10.1779

Gillam, B., & Nakayama, K. (2002). Subjective contours at line terminations depend on scene layout analysis, not image processing. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 43–53. doi: 10.1037/0096-1523.28.1.43

Grice, G.R., Canham, L., & Boroughs, J.M. (1983). Forest before trees? It depends where you look. *Perception & Psychophysics*, *33*, 121–128. doi: 10.3758/BF03202829

Han, S., & Humphreys, G.W. (1999). Interactions between perceptual organization based on Gestalt laws and those based on hierarchical processing. *Perception & Psychophysics*, *61*, 1287–1298. doi: 10.3758/BF03206180

Han, S., Humphreys, G.W., & Chen, L. (1999). Parallel and competitive processes in hierarchical analysis: perceptual grouping and encoding of closure. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 1411–1432. doi: 10.1037/0096-1523.25.5.1411

Han, S., Fan, S., Chen, L., & Zhuo, Y. (1997). On the different processing of wholes and parts: A psychophyiological analysis. *Journal of Cognitive Neuroscience*, *9*, 687–698. doi: 10.1162/jocn.1997.9.5.687

Han, S., Liu, W. Yund, E.W., & Woods, D.L. (2000). Interactions between spatial and global/local feature selection: An ERP study. *Neuroreport*, *11*, 2753–2758. doi: 10.1097/00001756-200008210-00029

Heinze H.J., Münte T.F. (1993). Electrophysiological correlates of hierarchical stimulus processing: dissociation between onset and later stages of global and local target processing. *Neuropsychologia*, *31*, 841–852. doi: 10.1016/0028-3932(93)90132-J

Hoffman, J.E. (1980). Interaction between global and local levels of a form. *Journal of Experimental Psychology: Human Perception and Performance, 6*, 222–234. doi: 10.1037/0096-1523.6.2.222

Hubner, R., & Volberg, G. (2005). The integration of object levels and their content: a theory of global/local processing and related hemispheric differences. *Journal of Experimental Psychology. Human Perception and Performance*, *31*, 520–541. doi: 10.3758/BF03193762

Hughes, H.C., Fendrich, R., & Reuter-Lorenz, P. (1990). Global versus local processing in the absence of low spatial frequencies. *Journal of Cognitive Neuroscience*, *2*, 272–282. doi: 10.1162/jocn.1990.2.3.272

Hughes, H.C., Layton, W.M., Baird, J.C., & Lester, L.S. (1984). Global precedence in visual pattern recognition. *Perception & Psychophysics, 35*, 361–371. doi: 10.3758/BF03206340

Hughes, H.C., Nozawa, G., & Kitterle, F.L. (1996). Global precedence, spatial frequency channels, and the statistic of the natural image. *Journal of Cognitive Neuroscience*, *8*, 197–230. doi: 10.1162/jocn.1996.8.3.197

Kanizsa, G. (1974). Contours without gradients or cognitive contours? *Italian Journal of Psychology*, *1*, 93–112.

Kimchi, R. (1992). The primacy of wholistic processing and global/local paradigm: A critical review. *Psychological Bulletin*, *112*, 24–38. doi: 10.1037/0033-2909.112.1.24

Kimchi, R. (1998). Uniform connectedness and grouping in the perceptual organization of hierarchical patterns. *Journal of Experimental Psy-*

chology: Human Perception and Performance, *24*, 1105–1118. doi: 10.1037/0096-1523.24.4.1105
Kimchi, R. (in press). The perception of hierarchical structure. In J. Wagemans (Ed.) Oxford handbook of perceptual organization. Oxford: Oxford University Press.
Kimchi, R., & Merhav, I. (1991). Hemispheric processing of global form, local form, and texture. *Acta Psychologica*, *76*, 133–147. doi: 10.1016/0001-6918(91)90042-X
Kimchi, R., & Razpurker-Apfeld, I. (2004). Perceptual grouping and attention: Not all groupings are equal. *Psychonomic Bulletin & Review*, *11*, 687–696. doi: 10.3758/BF03196621
Kinchla, R.A., & Wolfe, J.M. (1979). The order of visual processing: Top-down, bottom-up, or middle out. *Perception & Psychophysics*, *25*, 225–231. Doi: 10.3758/BF03202991
Kinchla, R.A., Macias, S.-V., & Hoffman, J.E. (1983). Attending to different levels of structure in a visual image. *Perception & Psychophysics*, *25*, 225–231. doi: 10.3758/BF03205860
Koivisto, M., & Revonsuo, A. (2004). Preconscious analysis of global structure: Evidence from masked priming. *Visual Cognition*, *11*, 105–127. doi: 10.1080/13506280344000266
LaGasse, L.L. (1993). Effects of good form and spatial frequency on global precedence. *Perception & Psychophysics*, *53*, 89–105. doi: 10.3758/BF03211718
Lamb, M.R., & Robertson, L. C. (1988). The processing of hierarchical stimuli: Effects of retinal locus, locational uncertainty, and stimulus identity. *Perception & Psychophysics*, *44*, 172–181. doi: 10.3758/BF03208710
Lamb, M.R., & Yund, L.C. (1996). Spatial frequency and attention: Effects of level-, target-, and location-repetition on the processing of global and local forms. *Perception & Psychophysics, 58*, 363–373. doi: 10.3758/BF03206812
Lamb, M.R., Pond, H.M., & Zahir, G. (2000). Contributions of automatic and controlled processes to the analysis of hierarchical structure. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 234–245. doi: 10.1037//0096-1523.26.1.234
Lesher, G.W., & Mingolla, E. (1993). The role of edges and line-ends in illusory contour formation. Vision Research, *33*, 2253–2270. doi: 10.1016/0042-6989(93)90104-5
Luna, D. (1993). Effects of exposure duration and eccentricity of global and local information on processing dominance. *European Journal of Cognitive Psychology*, *5*, 183–200. doi: 10.1080/09541449308520115
Martin, M. (1979). Local and global processing: The role of sparsity. *Memory and Cognition*, *7*, 476–484. doi: 10.3758/BF03198264
Mevorach, C., Humphreys, G.W., & Shalev, L. (2006). Effects of saliency, not global dominance, in patients with left parietal damage. *Neuropsychologia*, *44*, 307–319. doi: 10.1016/j.neuropsychologia.2005.04.015
Miller, J. (1981). Global precedence in attention and decision. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 1161–1174. doi: 10.1037/0096-1523.7.6.1161
Miller, J., & Navon, D. (2002). Global precedence and response activation: evidence from LRPs. *The Quarterly Journal of Experimental Psychology: A, Human Experimental Psychology*, *55*, 289–310. doi: 10.1080/02724980143000280
Murray, M.M., & Herrmann, C.S. (2013). Illusory contours: a window onto the neurophysiology of constructing perception. *Trends in Cognitive Sciences*, *17*, 471–481. doi: 10.1016/j.tics.2013.07.004
Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology*, *9*, 353–383. doi: 10.1016/0010-0285(77)90012-3
Navon, D. (1981). The forest revisited: More on global precedence. *Psychological Research*, *43*, 1–32. doi: 10.1007/BF00309635
Navon, D. (2003). What does a compound letter tell the psychologist's mind? *Acta Psychologica*, *114*, 273–309. doi: 10.1016/j.actpsy.2003.06.002
Palmer, T., Tzeng, O.J., & He S. (1995). Local-level and global-level form characteristics in apparent-motion correspondence. *Perception*, *24*, 1233–1245. doi: 10.1068/p241233
Paquet, L., & Merikle, P.M. (1984). Global precedence: The effect of exposure duration. *Canadian Journal of Psychology*, *38*, 45–53. doi: 10.1037/h0080783
Poirel N., Pineau A., Mellet E. (2008). What does the nature of the stimuli tell us about the Global Precedence Effect? *Acta Psychologica*, *127*, 1–11. doi: 10.1016/j.actpsy.2006.12.001
Robertson, L.C. (1996). Attentional persistence for features of hierarchical patterns. *Journal of Experimental Psychology: General*, *125*, 227–249. doi: 10.1037/0096-3445.125.3.227
Robertson, L.C., Lamb, M.R., & Zaidel, E. (1993). Interhemispheric relations in processing hierarchical patterns: Evidence from normal and commissurotomized subjects. *Neuropsychology*, *7*, 325–342. doi: 10.1037/0894-4105.7.3.325
Salvano-Pardieu, V. (2000). Spatial factors of brightness illusion in the Ehrenstein figure. *Perception*, *29*, 709–20. doi: 10.1068/p2922
Salvano-Pardieu, V., Wink, B., Taliercio, A., Manktelow, K., & Meigen, T. (2006). Can subthreshold summation be observed in the Ehrenstein illusion? *Perception*, *35*, 965–81. doi: 10.1080/13506280902949312
Schumann, F. (1900). Beiträge zur Analyse der Gesichtswahrnehmungen. Erste Abhandlung. Einige Beobachtungen über die Zusammenfassung von Gesichtseindrücken zu Einheiten. *Zeitschrift für Psychologie und Physiologie der Sinnesorgane*, *23*, 1–32.
Sebrechts, M.M., & Fragala, J.J. (1985). Variation on parts and wholes: Information precedence vs. global precedence. *Proceedings of the Seventh Annual Conference of the Cognitive Science Society*, 11–18.
Shipley, T.F., & Kellmann, P.J. (1992). Strength of visual interpolation depends on the ratio of physically specified to total edge length. *Perception & Psychophysics*, *52*, 97–106. doi: 10.3758/BF03206762
Shulman, G.L., Sullivan, M.A., Gish, K., & Sakoda, W.J. (1986). The role of spatial-frequency channels in the perception of local and global structure. *Perception*, *15*, 259–273. doi: 10.1068/p150259
Spillmann, L., & Dresp, B. (1995). Phenomena of illusory form: can we bridge between levels of explanation? *Perception*, *24*, 1333–1364. doi: 10.1068/p241333
Spillmann, L., & Ehrenstein, W.H. (2004). Gestalt factors in the visual neurosciences. In L. Chalupa & J.S. Werner (Eds.), *The visual neurosciences* (pp. 181–197). Cambridge: MIT Press.
Ward, L.M. (1982). Determinants of attention to local and global features of visual forms. *Journal of Experimental Psychology: Human Perception and Performance*, *8*, 562–581. doi: 10.1037/0096-1523.8.4.562
Weissman, D.H., & Woldorff, M.G. (2005). Hemispheric asymmetries for different components of global/local attention occur in distinct temporo-parietal loci. *Cerebral Cortex*, *15*, 870–876. doi: 10.1093/cercor/bhh187

ACKNOWLEDGMENTS
We wish to thank three anonymous reviewers for helpful comments on a former version of the manuscript. This research has been supported by the National Science Centre (Poland), and funded under the NSC decision DEC-2011/03/B/HS6/01022 to P.S.