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The role of visual awareness in processing of global structure: Evidence from the perceptual organization of hierarchical patterns

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ABSTRACT

We examined whether the perceptual organization of hierarchical structure, and specifically, the integration of local elements into a global shape, requires visual awareness, using a masked priming paradigm, sandwich masking to render the prime invisible, and two types of primes, many-element hierarchical patterns composed of many relatively small elements (Experiment 1) and few-element hierarchical patterns composed of a few relatively large elements (Experiment 2). A significant response priming of the local elements of many-element patterns was observed for invisible primes, whereas a significant response priming of the global shape was found *only* for the visible primes. For the few-element patterns, only significant response priming of the local elements was observed, as expected, for both visible and invisible primes. Our results suggest that local elements are represented in the absence of visual awareness, regardless of their number and relative size. Visual awareness, however, can be essential for grouping local elements into a global shape. The critical role of awareness in deriving global structure implies that global perception, which characterizes much of our early perception of objects and scenes, is likely to depend on visual awareness.

1. Introduction

The consciously perceived visual world is a meaningful scene that consists of distinct objects and surfaces. Perceptual organization is the process by which the disjoint bits and pieces of visual information are structured into the larger coherent units that we eventually experience as environmental objects. The Gestalt psychologists suggested that perceptual organization is achieved by a set of grouping principles, including proximity, good continuation, common fate, similarity, and closure (Wertheimer, 1923), and modern psychologists have added common region (Palmer, 1992) and element connectedness (Palmer & Rock, 1994). In addition, it has been suggested that perceptual organization involves two distinct processes: a process of unit formation or clustering that determines which elements belong together, and a process of shape formation or configuring that determines the shape of the grouped elements (Koffka, 1935; Rock, 1986). Progress has been made in elucidating the processes involved in perceptual organization (for reviews see, Peterson & Kimchi, 2013; Wagemans, Elder, et al., 2012; Wagemans, Felman, et al., 2012). Yet, the interplay between perceptual organization and visual awareness remains poorly understood.

Recent research has attempted to examine whether visual awareness of the stimulus is needed for it to be perceptually organized. The results suggest that it depends on the perceptual organizational processes under study, which is perhaps not surprising in light of the evidence that perceptual organization is a multiplicity of processes that vary in time course, developmental trajectory and attentional demands (e.g., Kimchi, 1998, 2000, 2009; Kimchi et al., 2005), and on the methods used to suppress the stimulus from awareness (e.g., Moors et al., 2016). These methods, which include, among others, sandwich masking (a combination of forward and backward masking), continuous flash suppression (CFS, a dynamic, high-contrast stimulus is presented to one eye to suppress the stimulus presented to the other eye), and metacontrast masking, apparently vary in the level at which the suppression takes place (for review see, Breitmeyer, 2015).

Thus, for example, it has been shown that grouping by proximity, luminance similarity, or connectedness can occur in the absence of visual awareness when the stimulus was rendered invisible by sandwich masking (Kimchi et al., 2018; Montoro et al., 2014) but not when it was rendered invisible by CFS (Kimchi et al., 2018). On the other hand, there is little evidence that illusory contours can be formed in the absence of visual awareness. No perception of illusory contours was found when Kanizsa-type inducers were suppressed from awareness by binocular rivalry (Sobel & Blake, 2003), CFS (Harris et al., 2011), sandwich

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masking or counter-phase flickering (Banica & Schwarzkopf, 2016). Regardless of the particular organization process, there is no evidence to date that any form of perceptual organization occurs during CFS, consistent with findings indicating that processing during CFS is rather limited (e.g., Moors et al., 2017).

In the present study we focused on the perceptual organization of hierarchical structure, examining whether local and global processing, and specifically, the integration of local elements into a global shape, can take place in the absence of visual awareness of the stimulus. The paradigm of hierarchical patterns – larger (global) figures constructed by suitable arrangement of smaller (local) figures (Navon, 1977) – has been extensively used to study global and local processing in conscious perception. Global advantage, i.e., faster responses to the global than the local level of hierarchical stimuli, is typically observed, to the limits of visibility and visual acuity. Yet, global advantage is not a rigid perceptual law. The effect can be modulated or even reversed (indicating local advantage) by several factors, such as overall size, spatial certainty, number and sparsity of the elements, exposure duration, goodness of form, and direct and indirect attentional manipulations (for reviews see, Kimchi, 1992, 2015; Navon, 2003). Furthermore, there are different kinds of wholes with different kinds of parts and part-whole relationships (e.g., a face with its parts versus a wall of bricks in which the bricks are mere constituents), weak or strong wholes, mere aggregation of elements or configurations that preempt the components, so that global advantage can characterize the processing of some visual objects but not of others (see Kimchi, 1992, 2015, for a discussion).

Only a few studies examined global and local processing in the absence of awareness. The results are inconsistent, probably due, at least partially, to the use of different stimuli and different methods to suppress the stimulus from awareness. In addition, some potential concerns appear to be associated with each study. Koivisto and Revonsuo (2004) used a masked priming paradigm to explore whether the global or the local level of hierarchical letters is processed when the prime is masked by interocular suppression. The main result was that only global primes facilitated identification of the target letter, but this occurred only when attention was selectively focused on, or biased to, the global level. Jimenez et al. (2017), using visual masking to render the prime invisible, found significant response priming for the global shape of the prime (global square or diamond made of local pacmen in different orientations) when the prime-mask SOA was 53 ms, but not when it was 27 ms. Both Jimenez and colleagues and Koivisto and Revonsuo tested prime visibility by an objective discrimination task that was administered after the masked priming block. The results suggested that not all participants performed at chance level, and furthermore, as is usually the case with the objective visibility test, there was no monitoring of individual trials, so it is possible that the prime was not invisible on all trials. Schwarzkopf and Rees (2011) presented participants with a prime – a shape defined either by position cues (small dots) or orientation cues (small oriented Gabor elements) – followed by a target shape (also defined by position or orientation cues) on which participants performed a shape-discrimination task. The prime was rendered invisible by counter-phase flickering. The results showed no priming of both position-defined shapes and orientation-defined shapes when retinotopic effects were ruled out, suggesting that local elements are not integrated into a global shape in the absence of awareness. Their results, however, may be confined to the specific stimuli they used, which involved a small number of (quite minimal) local elements forming a sparse global stimulus. In conscious perception, number and sparsity of local elements were found to modulate global advantage and even reverse it (e.g., Kimchi, 1998; Martin, 1979).

In our study we attempted to take care of some of these concerns. We used a masked priming paradigm and sandwich masking to render the prime invisible (with prime-mask SOA of 40 ms). The stimuli were hierarchical patterns, in which the local elements and the global shape were about equally complex and recognizable (e.g., a global square made of local triangles), of two types: many-element patterns composed of many, relatively small elements (Experiment 1), and few-element patterns composed of few, relatively large elements (Experiment 2). In both experiments, participants were presented with a masked prime followed by a clearly visible target. The target could be congruent or incongruent with the prime at the global or at the local level, thus allowing us to test congruency effects for each level separately. Awareness of the prime was assessed on each trial using a 4-point scale of subjective visibility, akin to the Perceptual Awareness Scale (PAS, Ramsøy & Overgaard, 2004), which was found to be as sensitive as measures relying on objective discrimination performance (e.g., Peremen & Lamy, 2014). The trial-by-trial measure of awareness allowed us to compare the influence of the prime on behavior when it is consciously perceived and when it is not, under identical stimulus conditions. Unconscious processing of the prime was measured as the performance difference between the incongruent and congruent conditions (i.e., response priming) on trials in which participants report no visibility.

Microgenetic studies of the perceptual organization of hierarchical patterns, using a primed-matching paradigm under conditions of awareness, revealed noticeable differences in the time course of the organization of many-element patterns versus few-element patterns (Kimchi, 1998). Priming of the global shape of many-element patterns was observed at brief exposures (40–90 ms), indicating an early and rapid grouping of the local elements into a global shape, whereas priming of the local elements was observed at longer exposures (within a time window of 190–390 ms). The converse was found for few-element patterns: Priming of the elements was observed at brief exposures (40–190 ms), indicating an early and rapid individuation of the local elements, whereas priming of the global shape was observed only at longer exposures (690 ms). In light of these findings, and the use of visual masking (that involves a brief exposure) to suppress the stimulus from awareness, we reasoned that many-element patterns are particularly suitable for examining whether the integration of local elements into a global shape can take place in the absence of visual awareness, whereas few-element patterns are particularly suitable for examining whether local processing can take place in the absence of visual awareness.

2. Experiment 1: global and local processing in many-element hierarchical patterns under sandwich masking

In this experiment we examined whether local and global processing in many-element patterns, and specifically the integration of the local elements into a global shape, can occur when the stimulus is suppressed from awareness by sandwich masking. If integrating local elements into a global shape does not require visual awareness, then response priming of the global shape should be observed regardless of prime visibility. However, if visual awareness is essential for the integration of elements into a global shape to occur, then response priming of the global shape should be observed only when the prime is reported visible. Note that according to the microgenetic findings, no response priming of the local elements of the many-element patterns is expected when the prime is reported visible, because no element priming was observed at brief exposure under conditions of awareness (Kimchi, 1998).

2.1. Method

2.1.1. Participants

Thirty-five students at the University of Haifa (32 right-handed, 26 females, age range = 19–32 years (M = 25.5)) participated in this experiment. All participants had normal vision, and were paid or granted with course credit for participation. All participants provided informed consent to a protocol approved by the Ethics Committee of the University of Haifa.

2.1.2. Apparatus

Stimuli were generated using Matlab R2014a and Psychophysics Toolbox (http://psychtoolbox.org). Experiments 1 and 2 were designed and stimulus presentation was controlled by E-Prime 2 software (Psychology Software Tools, Pittsburgh, PA). All stimuli were presented on an LCD BenQ monitor (24-in, 100-Hz refresh rate, 1920 × 1080 resolution). Participants provided responses using a response-box (Psychology software tools, model 200A) and a computer keyboard. Participants viewed the screen through a circular aperture (16 cm in diameter) of a matte black cardboard sheet. A chin rest was used to set the viewing distance to approximately 57 cm from the monitor. The testing room was dimly lit.

2.1.3. Stimuli

All stimuli were presented at the center of the screen on a grey background (RGB: 70,70,70; 18.2 cd/m^2). The prime was a global diamond made up of 12 relatively small stars or a global square made up of 12 relatively small triangles. The color of the contours of the stars and the triangles was light grey (RGB: 190,190,190; 58.9 cd/m^2). The side of the diamond subtended 4.71° and the side of the square subtended 4.8°. Each individual star element subtended 0.62° in height, and each individual triangle element subtended 0.58° in height; the contours of the elements were 3 pixels wide (see Fig. 1A).

There were two types of targets, defined by the level of congruency between the prime and the target, administered in separate blocks (see Fig. 1C). In the global block, prime-target congruency was at the global level, i.e., in the global shape. The target was a global diamond or a global square, each made up of 12 relatively small, task-irrelevant, circles. The side of the diamond and the side of the square subtended 2.86° and 2.8°, respectively. Each individual circle element subtended 0.34° in diameter, its contours were 2 pixels wide and their color was light grey (RGB: 190, 190, 190). In the local block, prime-target congruency was at the local level, i.e., in the shape of local elements. The target was a global, task-irrelevant, circle made up of 12 relatively small stars or 12 relatively small triangles. The global circle subtended 3.63° (in diameter), each individual star element subtended 0.45° in height and each individual triangle element subtended 0.41° in height; the contours of each element were 2 pixels wide, and their color was light grey (RGB: 190,190,190). Note that the target was presented at a different scale than the prime to avoid retinotopic effects. In each block, the targets were equally likely to be congruent or incongruent with the primes.

The forward and backward masks were patterns consisting of 100 grey (RGB 70,70,70) and light grey (RGB 190,190,190) lines randomly placed inside a square area subtended 7° × 7° (Fig. 1B). Each line subtended 1° in length and 4 pixels in width. The orientations of the lines were also random, but excluded orientations of 45° and its multiplications. During the experiment, each particular mask was randomly chosen from a pool of 50 masks and appeared just once in a trial.

2.1.4. Procedure and design

The sequence of events in each trial is shown in Fig. 1B. Each trial started with a fixation mark (1° × 1° light grey cross: RGB 210,210,210; 63.4 cd/m^2) presented at the center of the screen for 1000 ms. A forward mask then appeared for 100 ms, followed by a prime that appeared for 40 ms. Then a backward mask appeared for 60 ms, followed by the target, which remained on the screen until the participant responded or 2000 ms had elapsed. Participants had to discriminate

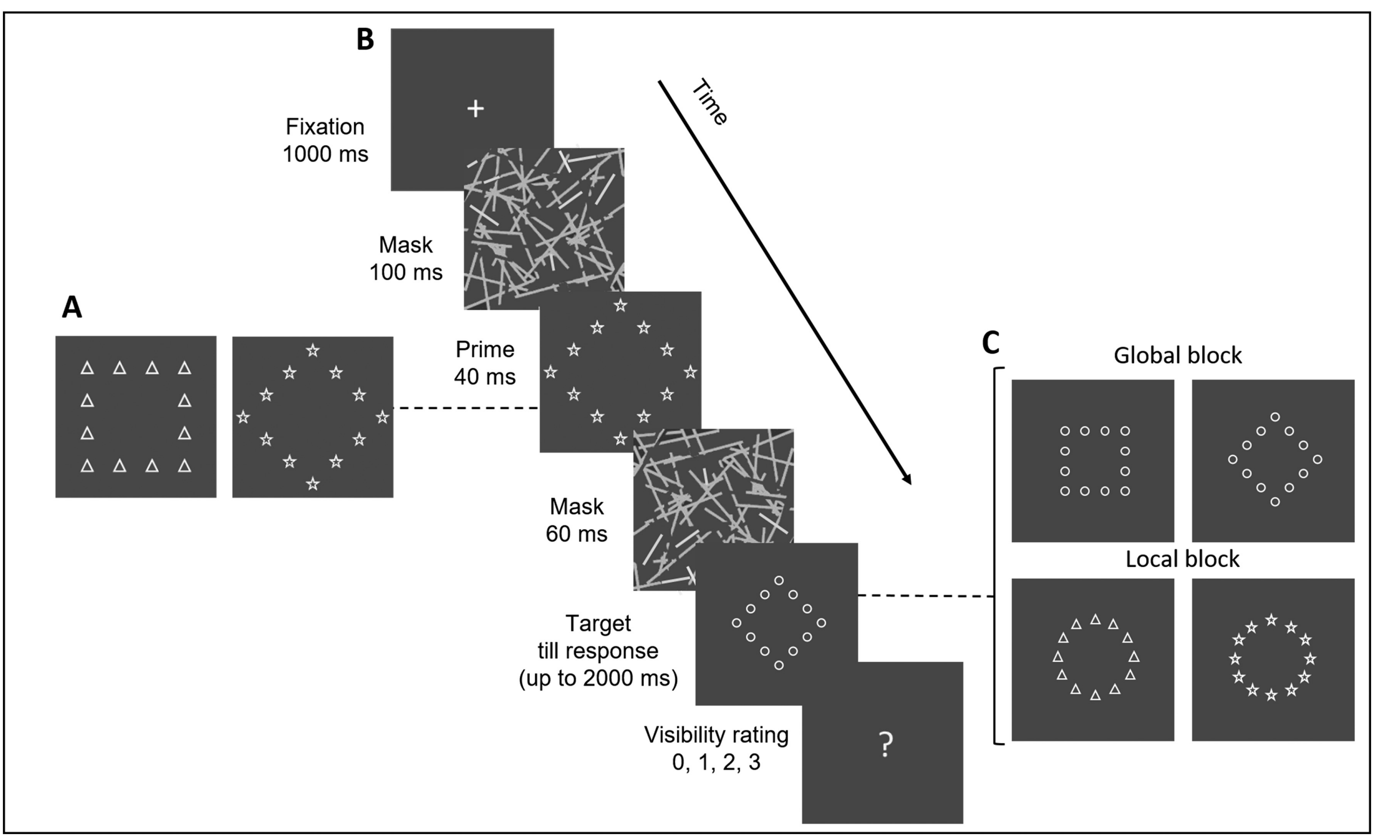

Fig. 1. Stimuli and sequence of events in Experiments 1. (A) Primes: relatively small stars forming a global diamond; relatively small triangles forming a global square. (B) Sequence of events in a trial: Prime was masked by forward and backward masks, followed by the target; prime-target congruency could be at the global shape (global block) or at the local elements (local block); participants were required to make a speeded discrimination response to the target and then rate subjective visibility of the prime. The example depicts a congruent trial in the global block. (C) Targets in the global block: relatively small, task-irrelevant circles forming a global square and a global diamond; targets in the local blocks: relatively small triangles and stars forming global, task irrelevant circles.

between the targets (global shapes in the global block, local shapes in the local block) by pressing one of two keys on the response-box with their dominant hand as fast as possible while avoiding making mistakes. The participants' response was followed by a question mark in the center of the screen, prompting the participants to provide subjective report of prime visibility. Participants rated their experience of prime visibility using a scale ranging from 0 (“I saw nothing”) to 3 (“I clearly saw a shape”) by pressing the “C”, “V”, “B” and “N” keys on the keyboard, which were covered by labels 0, 1, 2, and 3, respectively, using their other hand.

The experiment consisted of a global block and a local block, as described above, the order of which was counterbalanced across participants. Each block consisted of 264 experimental trials, including 24 catch trials in which no prime was presented, and was preceded by 48 practice trials. During the practice trials, an auditory tone provided immediate feedback after an incorrect response or when 2000 ms had elapsed with no response. There were two breaks within each block and one inter-block break, during which participants were instructed regarding their task in a next block.

2.1.5. Statistical methods

Several participants did not use all the possible visibility ratings, resulting in an unbalanced data structure. Therefore, we used a linear mixed-effects model (LMM) for repeated measures in all analyses involving visibility as a factor. All means reported in the article are least square means. All analyses were performed using SAS (version 9.4). When null effects were theoretically important (e.g., inferring that awareness is necessary for global or local processing to occur relies on null effects when the prime is reported invisible), we also evaluated evidence in favor of the null hypothesis over the alternative hypothesis by computing the Bayes factor (BF01) in Bayesian paired *t*-test, using JASP statistical software (www.jasp-stats.org) and a Cauchy prior centered on zero (scale = 0.707). Following current norms, we considered BF01 that exceeds 3 as providing evidence for the null hypothesis (with a BF01 between 3 and 10, 10 and 30, 30 and 100 and > 100 providing moderate, strong, very strong and extreme evidence, respectively; Jeffreys, 1961; Lee & Wagenmakers, 2013).

2.2. Results and discussion

The participants rated 56% of all catch trials with visibility rating 0, and only 8% with visibility rating 3. Catch trials were excluded from all analyses.

Mean proportions of trials at each level of prime visibility are presented in Fig. 2. The participants rated prime visibility as 0 on 52% of the trials, 1 on 25% of the trials, 2 on 13% of the trials and 3 on 10% of the trials.

In all response time (RT) analyses, trials in which responses to the target were incorrect (2.87% of trials) were excluded from the analysis. In addition, trials with RTs more than 2 SD from condition mean for each participant were trimmed (5.17% of correct trials). Mean RTs and accuracy for congruent and incongruent conditions in each visibility are presented in Table 1. Accuracy was high (mean = 97.13%) and there was no indication for speed-accuracy tradeoff. Therefore, accuracy is not discussed further.

A linear mixed-effects model for repeated measures with visibility (0, 1, 2, 3), congruency (congruent, incongruent) and globality (global shape, local elements) as within-subject factors was conducted on the RT data. The analysis showed a significant effect of visibility, $F(3,68) = 26.10$, $p < .0001$, indicating that responses were fastest on trials on which the prime was reported invisible (visibility rating 0), a significant effect of globality, $F(1,34) = 67.67$, $p < .0001$, which interacted with visibility, $F(3,58) = 26.42$, $p < .0001$, and a significant interaction between congruency and visibility, $F(3,65) = 3.88$, $p = .0129$. The three-way interaction between globality, congruency and visibility, $F(3,53) = 4.39$, $p = .0078$, was significant, suggesting

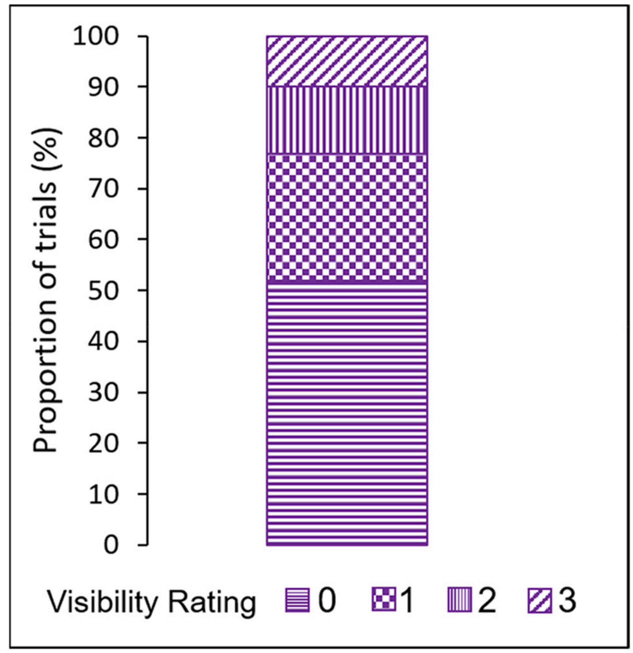

Fig. 2. Mean proportions of trials at each level of prime visibility Experiment 1.

Table 1
Mean (M) and standard error (SE) for RTs (ms) and Accuracy (%) in congruent and incongruent conditions for each level of visibility in the global and the local blocks in Experiment 1.

Visibility	RT				Accuracy			
	Congruent		Incongruent		Congruent		Incongruent	
	M	SE	M	SE	M	SE	M	SE
Global block								
0	661	22.3	666	22.3	97.6	1.1	96.8	1.1
1	682	22.8	670	22.8	97.4	1.2	97.3	1.2
2	677	23.5	705	23.6	95.9	1.3	96.9	1.3
3	630	24.1	649	24.2	98.4	1.6	97.9	1.6
Local block								
0	647	22.3	668	22.3	97.6	1.1	97.3	1.1
1	727	22.7	720	22.7	94.3	1.1	96.4	1.2
2	715	23.7	689	23.6	98.5	1.3	98.1	1.3
3	699	24.3	729	24.2	96.1	1.5	97.0	1.6

that the congruency effects differed for global shape and local elements and varied as a function of visibility.

The main objective of the present study was to examine whether the organization of local elements into a global shape requires visual awareness. Thus, the critical comparison is between response priming when participants were unaware of the prime (prime visibility rated 0) and when they were aware of it (prime visibility rated 3). Since there were not enough trials with visibility ratings 3 to allow meaningful analysis, we adopted a more conservative criterion for awareness and combined trials on which visibility was rated 2 or 3. Mean response priming for the global shape and the local elements as a function of visibility (0 vs. 2 + 3) are presented in Fig. 3. A linear mixed-effects model for repeated measures with visibility (0, 2 + 3), congruency (congruent, incongruent) and globality (global shape, local elements), showed significant effects of visibility, $F(1,24) = 6.38$, $p = .0186$, globality, $F(1,34) = 16.12$, $p = .0003$, and congruency, $F(1,34) = 8.71$, $p = .0057$, and a significant interaction between globality and visibility, $F(1,18) = 29.17$, $p < .0001$. Importantly, the interaction between globality, visibility and congruency was significant, $F(1,15) = 7.36$, $p = .0160$. Follow-up analyses revealed, as can be seen

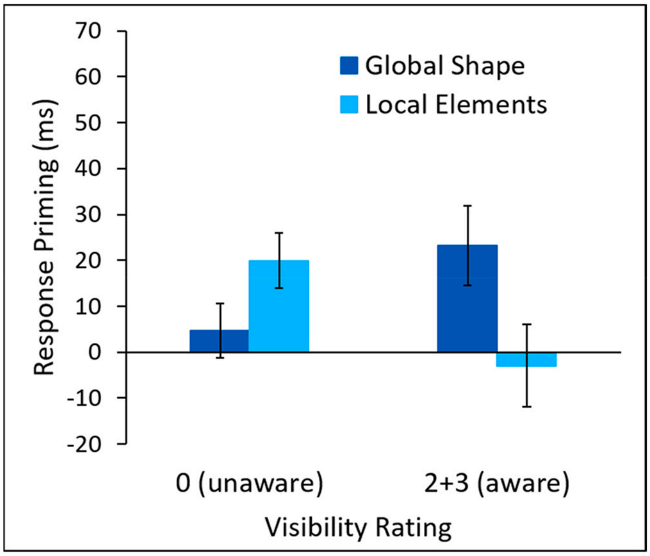

Fig. 3. Mean response priming (defined as the RT difference between incongruent and congruent conditions) for global shape and local elements as a function of visibility rating (0 vs. 2 + 3) in Experiment 1. Error bars represent standard error.

in Fig. 3, different patterns of results when participants were unaware of the prime (visibility rating 0) and when they were aware of the prime (visibility rating 2 + 3). A significant response priming of the local elements (averaged 20 ms) was observed for visibility rating 0, $F(1,15) = 11.00$, $p = .0047$. The response priming of the global shape for visibility rating 0 was not significant, $F < 1$; a Bayesian paired *t*-test showed that the evidence provides moderate support for the null hypothesis, BF01 = 3.356. In a clear contrast, a significant response priming of the global shape (averaged 23 ms) was found for visibility rating 2 + 3, $F(1,15) = 6.98$, $p = .0185$. No significant response priming of the local elements was observed for this visibility condition, $F < 1$; a Bayesian paired *t*-test provided moderate support for the null hypothesis, BF01 = 4.245.

Note that the results for visibility rating 1 (see Table 1) showed no significant response priming (with a negative tendency) of the global shape, $F(1,53) = 1.75$, $p = .1910$, or of the local elements, $F < 1$, presumably reflecting an "in between" state of some glimpses of awareness between purely unconscious processing and fully conscious processing (e.g., Overgaard et al., 2006).

The finding of a significant response priming of the local elements and no significant response priming of the global shape when visibility was null, is seen to suggest that the local elements are represented but they are not integrated into a global shape when the stimulus is suppressed from awareness by visual masking. When the prime was reported visible, a significant response priming of the global shape was observed. These findings suggest that integration of local elements into a global shape requires visual awareness. The present findings are in agreement with the findings of Schwarzkopf and Rees (2011), who used different stimuli and a different suppression method. It should be further noted that the finding of a significant response priming only of the global shape when the prime was reported visible is in agreement with the previous findings of Kimchi (1998). Using a primed-matching paradigm, Kimchi found that only the global shape of patterns containing many relatively small elements was primed at brief exposure; the local elements of such patterns were primed only at longer exposures, which were beyond the exposure used in the present experiment.

3. Experiment 2: global and local processing in few-element hierarchical patterns during sandwich masking

This experiment is similar to Experiment 1, except for the hierarchical stimuli, which were composed of a few, relatively large local elements. This experiment was designed mainly to examine whether local processing can occur in the absence of visual awareness. The results of Experiment 1 suggest that it can. If indeed local processing can occur without awareness, then the results of Experiment 2 for visibility rating 0 should agree with those of Experiment 1. Note that according to the microgenetic findings (Kimchi, 1998), no response priming of the global shape is expected for the few-element patterns even for visibility rating 2 + 3, because no organization into a global shape for these patterns was found at brief exposure when participants were aware of the stimulus; organization into a global shape of such patterns was evidenced only at longer exposures far beyond the one used in the present experiment.

3.1. Method

3.1.1. Participants

Thirty-four individuals (31 right-handed, 24 females, age range = 19–29 years (M = 25.6)) participated in Experiment 2. All participants had normal vision, and were paid or granted with course credit for participation. All participants provided informed consent to a protocol approved by the Ethics Committee of the University of Haifa.

3.1.2. Apparatus, stimuli, procedure and design

The apparatus and the procedure (Fig. 4B) were the same as in Experiment 1. The prime was a global diamond made up of 4 relatively large stars or a global square made up of 4 relatively large triangles (Fig. 4A). The color of the contour of the stars and triangles was light grey (RGB: 190,190,190). The side of the diamond subtended 4.14° and the side of the square subtended 4°. Each individual star element subtended 1.58° in height, and each individual triangle element subtended 1° in height; the contours of the elements were 3 pixels wide. In the global block, the targets were congruent with the primes in their global shape (Fig. 4C). The target was a global diamond or a global square, each made up of 4 relatively large, task-irrelevant circles, the color of their contour was light grey (RGB: 190,190,190). The side of the diamond subtended 1.7°, and the square subtended 1.7° X 1.7°. Each individual circle element subtended 0.58° in diameter, and the color of their contour was light grey (RGB: 190,190,190). In the local block, the targets were congruent to the primes in their local elements (Fig. 4C). One target consisted of 4 relatively large stars which were arranged in a task-irrelevant, T-like global shape that subtended 3.15° in width and 1.88° in height. Each individual star element subtended 0.87° in height, its contours were 2 pixels wide, and their color was light grey (RGB: 190,190,190). The other target consisted of 4 relatively large triangles that were also arranged in a task-irrelevant, T-like global shape, the width of which was 2.84° and its height was 1.8°. Each individual triangle element subtended 0.78°, its contours were 2 pixels wide and their color was light grey (RGB: 190,190,190). The masks were the same as in Experiment 1.

All other aspects of the procedure and design and statistical methods were the same as in Experiment 1.

3.2. Results and discussion

Two participants were excluded from the analysis because they gave visibility rating 3 on 100% and 98% of catch trials, respectively. The remaining 32 participants rated 54% of all catch trials with visibility rating 0, and only 10% of all catch trials with visibility rating 3. Catch trials were excluded from all analyses.

Mean proportions of trials at each level of prime visibility are presented in Fig. 5. The prime visibility was rated 0 on 47% of the trials, 1

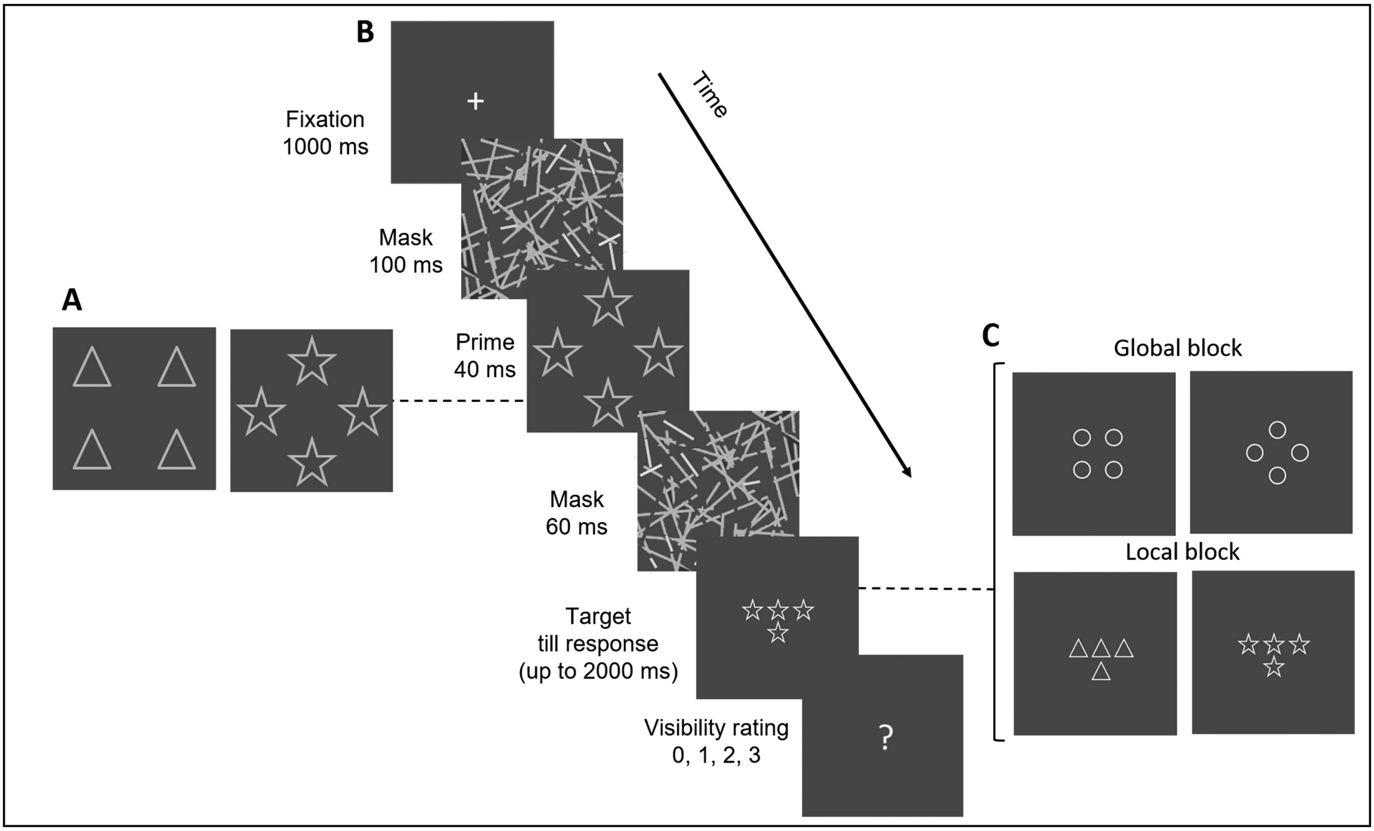

Fig. 4. Stimuli and sequence of events in a trial in Experiments 2. (A) Primes: relatively large stars forming a global diamond; relatively large triangles forming a global square. (B) Sequence of events in a trial: Prime was masked by forward and backward masks, followed by the target; prime-target congruency could be at the global shape (global block) or at the local elements (local block); participants were required to make a speeded discrimination response to the target and then rate subjective visibility of the prime. The example depicts a congruent trial in the local block. (C) Targets in the global block: relatively large circles forming a global square and a global diamond; target in the local block: relatively large stars and triangles forming a global T-like shape.

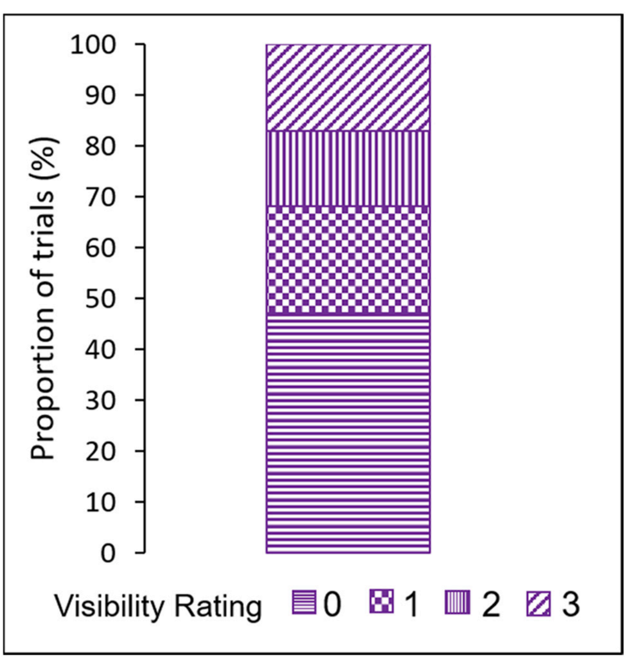

Fig. 5. Mean proportions of trials at each level of prime visibility in Experiment 2.

on 21% of the trials, 2 on 15% of the trials, and 3 on 17% of the trials.

Trials in which responses to the target were incorrect (3.45% of trials) were excluded from all analyses. In addition, trials with RTs more than 2 SD from condition mean for each participant were trimmed (5.25% of correct trials). Mean RTs and accuracy for congruent and incongruent conditions in each visibility are presented in Table 2. Accuracy was high (mean = 96.55%) and there was no indication for speed-accuracy tradeoff. Therefore, accuracy is not discussed further.

Table 2
Mean (M) and standard error (SE) for RTs (ms) and accuracy (%) in congruent and incongruent conditions for each level of visibility in the global and the local blocks in Experiment 2.

Visibility	RT				Accuracy			
	Congruent		Incongruent		Congruent		Incongruent	
	M	SE	M	SE	M	SE	M	SE
Global block								
0	696	24	708	24	95.9	1.3	95.7	1.3
1	735	24.6	726	24.7	97.8	1.4	96.9	1.4
2	769	25.4	759	25.4	94.2	1.5	97.9	1.5
3	668	25.2	690	25.1	98.1	1.6	95.3	1.6
Local block								
0	638	24	663	24	96.4	1.3	96.1	1.3
1	769	24.8	754	24.8	98.2	1.4	96.7	1.4
2	750	25.5	793	25.2	97.1	1.5	96.9	1.5
3	693	25.2	746	25.4	95.9	1.6	95.2	1.6

A linear mixed-effects model for repeated measures with visibility (0, 1, 2, 3), congruency (congruent, incongruent) and globality (global shape, local elements) as within-subject factors was conducted on the RT data. The analysis showed a significant effect of visibility, $F(3,76) = 78.11$, $p < .0001$, indicating that responses were fastest on

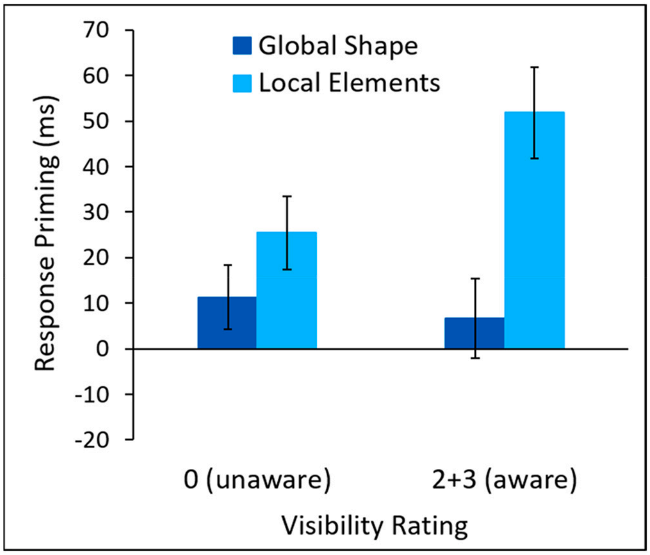

Fig. 6. Mean response priming (defined as the RT difference between incongruent and congruent conditions) for global shape and local elements as a function of visibility rating (0 vs. 2 + 3) in Experiment 2. Error bars represent standard error.

trials on which the prime was reported invisible (visibility rating 0), a significant effect of congruency, $F(1,31) = 13.81$, $p = .0008$, which interacted with visibility, $F(3,69) = 5.93$, $p = .0012$, a significant interaction between globality and visibility, $F(3,57) = 38.30$, $p < .0001$, and a significant interaction between globality and congruency, $F(1,31) = 8.01$, $p = .0081$. The three-way interaction between globality, congruency and visibility, was not significant, $F(3,50) = 1.98$, $p = .1289$.

Here again we were interested in the comparison between response priming when participants were unaware of the prime (prime visibility rated 0) and when they were aware of it (prime visibility rated 3). As in Experiment 1, there were not enough trials with visibility ratings 3 to allow meaningful analysis, and therefore we again adopted a more conservative criterion for awareness and combined trials on which visibility was rated 2 or 3. Mean response priming for the global shape and the local elements as a function of visibility are presented in Fig. 6. A linear mixed-effects model for repeated measures with visibility (0, 2 + 3), congruency (congruent, incongruent) and globality (global shape, local elements) as within-subject factors, showed significant effects of visibility, $F(1,27) = 60.94$, $p < .0001$, globality, $F(1,31) = 12.09$, $p = .0015$, and congruency, $F(1,31) = 34.13$, $p < .0001$, and a significant interaction between globality and visibility, $F(1,16) = 71.00$, $p < .0001$. The interaction between congruency and globality was significant, $F(1,31) = 13.26$, $p = .0010$, and did not vary significantly with visibility, $F(1,15) = 3.63$, $p = .0760$. As can be seen in Fig. 6, significant response priming of the local elements was observed for visibility rating 0 (averaged 25 ms), $F(1,15) = 12.49$, $p = .0030$, and for visibility rating 2 + 3 (averaged 52 ms), $F(1,15) = 33.65$, $p < .0001$. The latter was significantly larger than the former, $F(1,19) = 6.25$, $p = .0217$, suggesting that visual awareness enhanced the representation of the local elements. No significant response priming of the global shape was found either for visibility rating 0, $F(1,15) = 2.31$, $p = .1494$, or for visibility rating 2 + 3, $F < 1$. Bayesian paired *t*-tests provided moderate support for the null hypotheses, BF01 = 4.734, and BF01 = 4.198, for visibility rating 0 and for visibility rating 2 + 3, respectively.

Similar to the results for visibility level 1 in Experiment 1, no significant response priming (with negative tendency) was observed for visibility level 1 (see Table 2), either of the local elements, or of the global shape, $F(1,50) = 1.47$, $p = .2311$, $F < 1$, respectively.

The finding of significant response priming for the local elements when prime's visibility was null replicates the finding of Experiment 1, indicating that local processing can occur in the absent of visual awareness, regardless of the number and the relative size of the local elements. The finding of significant response priming for the local elements, but not for the global shape, when the prime was reported visible, is in agreement with previous findings of Kimchi (1998), who demonstrated, using primed-matching paradigm, that only the local elements of patterns containing a few, relatively large elements were primed at brief exposures (the global shape was primed only at longer exposures) under condition of visual awareness.

4. General discussion

In this study we examined whether the perceptual organization of hierarchical structure, and specifically, the integration of local elements into a global shape, can take place in the absence of visual awareness of the stimulus. To this end we used a masked priming paradigm in which the prime was rendered invisible by sandwich masking, and two types of primes, many-element hierarchical patterns (Experiment 1) and few-element hierarchical patterns (Experiment 2). The targets could be congruent with the primes either at the global level (i.e., the global shape) or at the local level (i.e., the shape of the local elements), thus allowing us to test response priming for each level separately.

The results showed significant response priming of the local elements of many-element and few-element hierarchical patterns when the primes were reported invisible, suggesting that the local elements are represented in the absence of visual awareness, regardless of their number and relative size. In the case of few-element patterns, significant response priming of the local elements was observed also when the prime was reported visible, the magnitude of which was significantly larger than the one for invisible prime, suggesting that awareness can enhance the representation of a few, relatively large elements.

Significant response priming of the global shape, however, was observed only when the many-element prime was reported visible. No significant response priming of the global shape was found when the prime was reported invisible, suggesting that grouping local elements into a global shape cannot occur without visual awareness.

One may argue that we cannot assume that global shapes and local elements are equally sensitive to sandwich masking, nor do we know the basis for the participants' subjective visibility ratings. Therefore, the argument goes, our results – the presence of local priming and absence of global priming when prime visibility was rated 0 – are not necessarily a function of awareness or unawareness of the prime (as indicated by visibility rating), but rather, they can be a function of higher vulnerability of the global shape to sandwich masking combined with a global bias in reporting visibility, such that rating prime visibility as 0 may be based on invisibility of global shape while the local elements were actually visible. This alternative account, however, is not very plausible and can be ruled out on several grounds. First, masking is more effective in suppressing stimulus visibility when the masks are similar to the masked stimulus (Breitmeyer & Ogmen, 2006). So if anything, our masks (relatively short oriented lines) were more likely to mask the local elements than the global shapes. Second, the instructions for rating the prime's visibility emphasized very clearly that visibility refers to any shape, small or large, besides the lines (of the mask, which always appeared). Hence, it is quite unlikely that participants interpreted the instructions for visibility rating as visibility of global shape. Third, we employed two blocks of trials, a global block in which participants had to respond to the target's global shape, and a local block in which they had to respond to the target's local elements. Namely, participants were directed to the global shape in one block and to the local elements in the other blocks, and this was counter balanced between participants, so there was nothing in the design that could bias the participants to the global shape. Finally, the results show no difference, in both experiments, in the percentage of trials at each level of prime's visibility, including visibility level 0, between the global and the local blocks (Experiment 1 visibility rating 0: 53% and 51% for the global and local block, respectively, χ^2 (1) = 0.038, p = .8445; Experiment 2 visibility rating 0: 45%and 49% for the global and local block, respectively, χ^2 (1) = 0.170, p = .6799). Thus, although it is possible that global shape and local elements may be differentially susceptible to masking, and subjective visibility rating may be biased, our masking was not more likely to suppress the visibility of the global shape than the visibility of the local elements, there was nothing in our design and instructions that could bias the participants to the global shape, and the results indicate no global bias in visibility rating. Therefore, our results are likely a function of awareness/unawareness of the prime.

The finding that grouping local elements into a global shape cannot occur without visual awareness is in agreement with that of Schwarzkopf and Rees (2011), who also showed no integration of local elements (small dots or oriented Gabor patches) into a global shape when the stimulus was suppressed from awareness by counter-phase contrast flickering. Our results appear to disagree with previous studies demonstrating organization of elements into a global shape in the absence of visual awareness (Jimenez et al., 2017; Koivisto & Revonsuo, 2004). But as noted earlier, we attempted to avoid some of the concerns associated with these studies. Thus, our results were obtained with prime-target SOA of 40 ms, and with a trial by trial monitoring of prime visibility. In addition, Koivisto and Revonsuo's finding of unconscious processing of the global level of hierarchical stimuli appears to be contingent on focusing attention on the global shape, making it difficult to disentangle effects of awareness from effects of attention.[1]

It seems reasonable then to conclude that the present study along with Schwarzkopf and Rees's study, which used different stimuli and different suppression methods, provide converging evidence that visual awareness is essential for the integration of local elements into a global shape. This is not to say that grouping of many relatively small elements into a cluster (i.e., grouping in the sense of clustering) does not take place without awareness. Rather, clustering does seem to occur, as previous findings indicate that basic grouping takes place without awareness (e.g., Kimchi et al., 2018; Montoro et al., 2014). It is the shape formation process that appears to require visual awareness.

It should be further noted, however, that certain grouping of local elements into a global shape can occur without awareness. Thus, Devyatko et al. (2019), using line configurations, the organization of which is based on good continuation, closure and symmetry, and sandwich masking to render the prime invisible, found significant response priming of the global shape for visible and invisible primes, though awareness appeared to enhance the representation of the global configuration. Breitmeyer et al. (2005), who used metacontrast masking to suppress the stimulus from awareness, also found unconscious representations of squares and diamonds composed of “corners”. Presumably, the process of shape formation can vary in complexity, and when the process is relatively simple, as when the contours of the global shape can be easily formed based on collinearity (e.g., Breitmeyer et al., 2005; Devyatko et al., 2019; Hadad & Kimchi, 2008; Kimchi, 2000), it can be accomplished in the absence of awareness. Interestingly, it has been also demonstrated that the complexity of the processes involved in perceptual organization affects its attentional demands and time course (e.g., Kimchi & Razpurker-Apfeld, 2004; Rashal et al., 2017; Razpurker-Apfeld and Kimchi, 2007).

Our findings for visible primes replicate previous findings demonstrating the critical role of number and relative size of the local elements in the early organization of hierarchical patterns (Kimchi, 1998; Kimchi et al., 2005): Global dominance for the many-elements patterns, consistent with the global advantage typically observed in the hierarchical stimuli paradigm (Navon, 1977), and local dominance for the few-element patterns.

The global dominance observed in conscious perception has been attributed by several researchers to privileged access of global representation computed unconsciously into consciousness (Hochstein & Ahissar, 2002; Treisman, 1986). Thus, according to the Hochstein and Ahissar's Reverse Hierarchy Theory, during initial unconscious, implicit bottom-up processing, local information encoded in low-level visual areas is combined in high-level visual areas into global information. This global information becomes conscious, whereas the local information becomes explicit only if required by current tasks. However, the present finding that only local elements are represented in the absence of awareness and the global shape is represented only in the presence of awareness, suggests that at least some integration of local information into global information does not take place unconsciously. Rather, visual awareness has a critical role in deriving global structure, such as a global shape, presumably involving perceptual-organization processes (e.g., Han et al., 1999; Kimchi, 1994, 1998, 2015).

5. Concluding remarks

To summarize, our findings demonstrate that local elements are represented in the absence of visual awareness, regardless of their number and relative size. Visual awareness, however, can be essential for the grouping of local elements into a global shape. The role of awareness in deriving global structure suggests that global perception, which characterizes much of our early perception of objects and scenes (e.g., De Cesarei & Loftus, 2011; Kimchi, 1998; Navon, 1977; Schyns & Oliva, 1994), is likely to be dependent on visual awareness.

CRediT authorship contribution statement

Ruth Kimchi conceived the idea for the study. **Ruth Kimchi, Shahar Sabary, and Dina Devyatko** designed the Experiments. **Shahar Sabary** programmed the experiments, and collected and analyzed the data. **Ruth Kimchi, Shahar Sabary, and Dina Devyatko** interpreted the data. **Shahar Sabary** wrote a very first draft of the manuscript. **Ruth Kimchi** critically and substantially revised the manuscript. **Ruth Kimchi** supervised the study.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2020.104442.

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[1] The relationship between attention and consciousness, which has been a matter of a lively debate in the last two decades, is beyond the scope of this paper. It suffices to say that we acknowledge the intimate relation between the two, and hold the view that attention may be necessary, but not sufficient, for awareness (e.g., Cohen et al., 2012).

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