Consciousness and Cognition 60 (2018) 37–51

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Can perceptual grouping unfold in the absence of awareness? Comparing grouping during continuous flash suppression and sandwich masking

Ruth Kimchi*, Dina Devyatko, Shahar Sabary

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

ARTICLE INFO

Keywords:
Perceptual grouping
Visual awareness
Visual masking
Continuous flash suppression
Unconscious grouping
Response priming

ABSTRACT

In this study we examined whether grouping by luminance similarity and grouping by connectedness can occur in the absence of visual awareness, using a priming paradigm and two methods to render the prime invisible, CFS and sandwich masking under matched conditions. For both groupings, significant response priming effects were observed when the prime was reported invisible under sandwich masking, but none were obtained under CFS. These results provide evidence for unconscious grouping, converging with previous findings showing that visual awareness is not essential for certain perceptual organization processes to occur. They are also consistent with findings indicating that processing during CFS is limited, and suggest the involvement of higher visual areas in perceptual organization. Moreover, these results demonstrate that whether a process can occur without awareness is dependent on the level at which the suppression induced by the method used for rendering the stimulus inaccessible to awareness takes place.

1. Introduction

Our conscious perception is of a seamless whole rather than of bits of obscured, colored blobs of light. Perceptual organization is the process by which the disjoint bits of visual information are structured into a meaningful scene composed of objects and their interrelations. The Gestalt psychologists, who were the first to study perceptual organization, suggested that perceptual organization occurs in accordance to a set of grouping and segregation principles. These include classic principles such as proximity, similarity, good continuation, common fate, and closure (Wertheimer, 1923), and new principles such as generalized common fate (Sekuler & Bennett, 2001), synchrony (Alais, Blake, & Lee, 1998), common region (Palmer, 1992), and element connectedness (Palmer & Rock, 1994) (for reviews see, Peterson & Kimchi, 2013; Wagemans et al., 2012).

An important issue concerns the role of consciousness in perceptual organization: Can perceptual organization unfold in the absence of visual awareness[1] of the stimulus? A number of studies have addressed this question, and the picture that emerges is far from being consistent. The inconsistency in the findings may not be so surprising in light of the evidence that perceptual organization is a multiplicity of processes (Behrmann & Kimchi, 2003; Kimchi, 2003), which vary in their time course (e.g., Hadad & Kimchi, 2008; Kimchi, 1998, 2000; Kurylo, 1997; Razpurker-Apfeld & Kimchi, 2007), developmental trajectory (e.g., Hadad, Maurer, & Lewis, 2010; Kimchi, Hadad, Behrmann, & Palmer, 2005; Quinn & Bhatt, 2006), and attentional demands (e.g., Freeman, Sagi, & Driver,

* Corresponding author at: Department of Psychology and Institute of Information Processing and Decision Making, University of Haifa, Haifa 3498838, Israel.
E-mail address: rkimchi@univ.haifa.ac.il (R. Kimchi).

[1] In this article, we use the terms "consciousness" and "awareness" interchangeably.

https://doi.org/10.1016/j.concog.2018.02.009
Received 6 November 2017; Received in revised form 23 February 2018; Accepted 24 February 2018

2001; Kimchi & Razpurker-Apfeld, 2004; Mack, Tang, Tuma, & Kahn, 1992; Moore, Grosjean, & Lleras, 2003; Rashal, Yeshurun, & Kimchi, 2017a), and may operate both early and late in the course of visual processing (e.g., Palmer, Brooks, & Nelson, 2003) (for reviews see, Gillebert & Humphreys, 2015; Kimchi, 2009, 2012; Quinn & Bhatt, 2015).

It is possible, then, that visual consciousness of the stimulus is essential for some perceptual organization processes, but not for others. For example, Montoro, Luna, and Ortells (2014), using a masked priming procedure, showed that grouping elements by proximity and by luminance similarity into horizontally or vertically oriented patterns can take place in the absence of visual consciousness. Schwarzkopf and Rees (2011), on the other hand, failed to find evidence for the grouping of local elements into a global shape in the absence of awareness. Recently, however, Jimenez, Montoro, and Luna (2017) found that elements can group into a global shape for prime-mask SOA of 53 ms, but not for SOA of 27 ms. Sweeny, Grabowecky, and Suzuki (2011) found that closed-curvature aftereffects, in contrast to open-curvature aftereffects, occurred only when observers were aware of the adaptor. Interestingly, even when the same organization process was examined – the formation of illusory Kanizsa configuration – the findings are mixed, presumably due to different methods used to suppress the stimulus from awareness. Sobel and Blake (2003) showed that binocular rivalry suppression prevented the formation of subjective contours. Similarly, Harris, Schwarzkopf, Song, Bahrami, and Rees (2011), using continuous flash suppression (CFS, an interocular masking technique in which a high contrast rapidly changing stimulus presented to one eye suppresses perception of a stimulus presented to the other eye; Tsuchiya & Koch, 2005), showed that awareness of inducers was necessary for perception of illusory contours. Similar findings were reported by Banica and Schwarzkopf (2016) using masking. In contrast, Wang, Weng, and He (2012), using breaking continuous flash suppression (b-CFS, a variant of CFS that entails measuring the time it takes stimuli to break suppression), found that a Kanizsa triangle emerged from suppression significantly faster than a control stimulus in which the local pacmen were randomly or 180° rotated, presumably suggesting formation of illusory contours without awareness (but see Moors, Wagemans, van Ee, & de-Wit, 2016). Also, Poscoliero, Marzi, & Girelli (2013), using metacontrast masking, and Jimenez et al. (2017), using sandwich masking (a combination of forward and backward masking), showed that masked Kanizsa configurations can have an influence on a subsequent shape discrimination, and Lau and Cheung (2012), demonstrated that illusory contour formation survives crowding of the inducers.

Hence, the question is which perceptual organization processes can occur without awareness of the stimulus, and to what extent does the answer to this question depend on the method used to suppress the stimulus from awareness (see Moors et al., 2016).

This study aimed to examine whether perceptual grouping can occur in the absence of visual awareness, using two different methods to suppress the stimuli from awareness. We focused on two basic grouping principles, the classic principle of grouping by luminance similarity (Experiments 1 and 3), and the new principle of grouping by element connectedness (Experiments 2 and 4). The similarity principle states that the most similar elements (in this case in luminance) tend to be grouped together. The principle of element connectedness states that elements that are connected tend to be grouped together.

Each grouping process was examined with two invisibility-inducing methods: CFS and sandwich masking (a combination of forward and backward masking). In all experiments, participants were presented with a liminal prime – dots grouped by luminance similarity or by connectedness into columns/rows – followed by a clearly visible target consisted of lines, the orientation of which was either congruent or incongruent with the prime's orientation. For each process under examination, the stimuli and the task were identical across the two methods. This is important because it can help to disentangle the limits of the method used to render the stimulus invisible and the limits of unconscious processing per se (Faivre, Berthet, & Kouider, 2012; Peremen & Lamy, 2014a).

Awareness of the prime was assessed on each trial using a sensitive subjective visibility scale akin to the Perceptual Awareness Scale (e.g., Ramsøy & Overgaard, 2004). Previous research has suggested that subjective reports of conscious perception can be as sensitive as measures relying on objective discrimination performance, provided that the subjective measure employed is not dichotomous (e.g., Peremen & Lamy, 2014b). 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 congruent and incongruent conditions (i.e., a response priming effect) on trials in which participants report no visibility.

If awareness of the stimulus is not essential for grouping to occur, then response priming is expected to be observed regardless of the stimulus visibility. If, on the other hand, awareness is essential for grouping to be accomplished, then response priming should be observed when the prime is visible, but not when the prime is reported invisible. Dependency of the results on the method used to render the prime invisible (CFS vs. visual masking), can tell us both about the level of suppression induced by each method, and about the level of processing of each of these groupings.

2. Experiment 1: Grouping by luminance similarity during CFS

In this experiment we examined whether grouping elements by luminance similarity into columns/rows can take place in the absence of awareness, by testing for response priming effects when the prime is rendered invisible by CFS. As noted earlier, grouping by luminance similarity in absence of conscious perception was examined by Montoro et al. (2014), using sandwich masking to render the stimulus invisible. In the present study we not only employed a different method to induce stimulus invisibility, but we also used a trial-by-trial subjective measure of prime visibility, unlike Montoro et al. (2014) who used a forced-choice prime discrimination task in a separate block and a forced-choice prime detection task on a separate sample of participants to obtain objective indices of prime visibility.

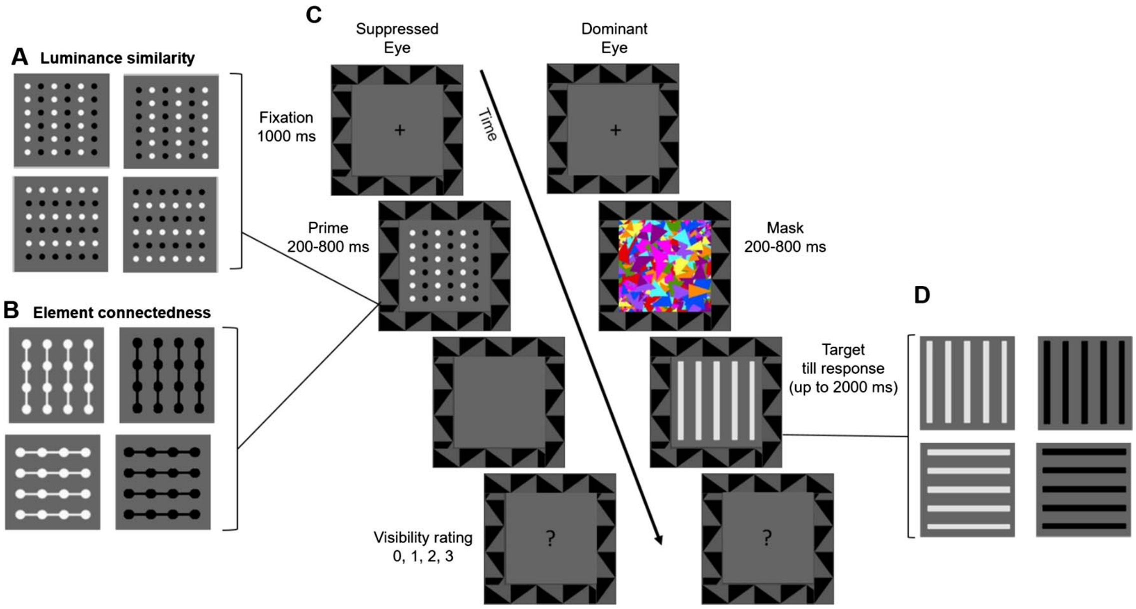

Fig. 1. Stimuli and sequence of events in Experiments 1 and 2. (A) Primes used in Experiment 1: columns/rows grouped by luminance similarity. (B) Primes used in Experiment 2: columns/rows grouped by elements connectedness. (C) Sequence of events in Experiments 1 and 2: The prime was gradually introduced to the suppressed eye, while the dynamic Mondrian was flashed at 10 Hz to the dominant eye, followed by the target. Participants made a speeded response to the target orientation (vertical or horizontal) and then rated visibility of the prime. The example depicts a congruent trial in Experiment 1 (grouping by luminance similarity). (D) Targets used in Experiments 1; the targets in Experiment 2 were identical except for the number of lines (4 rather than 5, see text for details).

2.1. Method

2.1.1. Participants

Participants in all the experiments were students at the University of Haifa 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. All had normal vision, and none participated in more than one experiment. We aimed at 16–20 participants after exclusion, to match the sample size typically used in studies examining unconscious processing, using CFS and masking.

Twenty-three individuals (20 right-handed, 21 females; age range = 18–29 years) participated in Experiment 1.

2.1.2. Apparatus

Stimuli were generated using Matlab R2014a and Psychophysics Toolbox (http://psychtoolbox.org) and were presented on an LCD BenQ monitor[2] (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. All stimuli were viewed through an adjustable mirror stereoscope attached to a chin rest at a distance of 57 cm. The testing room was dimly lit.

2.1.3. Stimuli

A black and grey mosaic frame (8.5° × 8.5°, with a thickness of 1.25°) was presented to both eyes throughout the trials to facilitate binocular fusion. All stimuli were presented centrally on a grey background (RGB 70, 70, 70; 18.2 cd/m^2) within the frame (Fig. 1C). The prime subtended 4.25° × 4.25°, and consisted of a matrix of 6 × 6 circle elements, 18 dark (RGB 30, 30, 30; 7.44 cd/m^2) and 18 light (RGB 110, 110, 110; 31.2 cd/m^2), which were grouped into columns or rows by luminance similarity (Fig. 1A). Each circle subtended 0.35° in diameter and the distance between vertically or horizontally adjacent circles subtended 0.43°. The target subtended 5° × 5° and consisted of 5 vertical or horizontal lines, all of which were either dark (RGB 10, 10, 10; 2.73 cd/m^2) or light (RGB 225, 225, 225; 74.5 cd/m^2). Each line in the target was 5° in length and 0.42° in width (Fig. 1D). A target and a prime could be congruent in their orientation (e.g., a columns prime and a vertical target) or incongruent (e.g., a columns prime and a horizontal target). The CFS mask was a high-contrast, Mondrian-like pattern (5.74° × 5.74°), which consisted of 1000 colored and randomly positioned triangles (0.4–2.2% of the mask size). The refresh rate of the CFS mask was set at 10 Hz. During the experiment, each particular mask was randomly chosen from a pool of 1000 masks and appeared just once.

[2] Some concerns have been raised about the suitability of LCD monitors for visual experiments because of some spatial and temporal imperfections, mostly affecting peripheral presentation (Ghodrati, Morris, & Price, 2015; but see Lagroix, Yanko, & Spalek, 2012). However, there is no such evidence for BenQ monitors, and tests in our lab of the BenQ monitor have suggested that it is a suitable alternative to CRTs.

2.1.4. Procedure and design

Prior to the experiment, we checked the participant's dominant eye using the Distance-Hole-In-The-Card test (e.g., https://www.wikihow.com/Determine-Your-Dominant-Eye), and calibrated the stereoscope for each participant using a custom program in Matlab with a Julesz's (1960) stereo pair (producing perception of a 3D square when the two patterns are fused).

The sequence of events in a trial is shown in Fig. 1C. Each trial started with the presentation of a fixation mark ($0.5^{\circ} \times 0.5^{\circ}$ black cross) for 1000 ms. Then a prime was presented to the suppressed eye, gradually increasing its contrast from 0 to 100% during the first 100 ms. A CFS mask (full contrast) was simultaneously presented to the dominant eye. The prime and mask remained on the screen until the target appeared in the dominant eye, following a variable SOA of 200, 400, 600, or 800 ms. The target remained present until the participant responded or 2000 ms had elapsed. Participants had to indicate the orientation of the target lines (vertical or horizontal) by pressing one of two keys on the response-box with their right hand as fast as possible while avoiding making mistakes. The response was followed by presentation of a question mark, prompting the participants to provide subjective report of prime visibility. Participants rated the prime visibility using a scale ranging from 0 ("I saw nothing") to 3 ("I clearly saw a pattern of circles") 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 left hand.

All the combinations of prime grouping (columns, rows), prime color arrangement (alternating light/dark or dark/light), target orientation (vertical, horizontal), target color (dark, light), and SOA (200, 400, 600, 800 ms) were presented with equal frequency in a random order. Prime and target were equally likely to be congruent or incongruent in their orientation. Each participant completed 688 trials, including 48 catch trials in which no prime was presented, divided into 8 blocks. The experimental trials were preceded by 64 practice trials. During the practice, an auditory tone provided immediate feedback after an incorrect response or when 2000 ms had elapsed with no response.

2.1.5. Data analysis

Exclusion of participants. Participants were excluded from the analyses based on their performance on catch (prime absent) trials, indicating visibility rating 3 on more than 20% of catch trials, or visibility rating 2 on more than 60% of catch trials combined with no (or very few) visibility rating 0. Participants who did not experience suppression, indicating visibility rating 3 on more than 65% of prime-present trials, were also excluded from the analyses.

Exclusion of trials. Catch trials were excluded from all analyses. In all reaction time (RT) analyses, only data from trials with correct responses to the target were analyzed; trials in which responses were incorrect were excluded. In addition, correct response trials with RTs more than 2 SD from condition mean for each participant were trimmed.

Statistical methods. In each of the four experiments reported here, several participants did not use all the possible visibility ratings, resulting in an unbalanced data structure (see supplemental figures). Therefore, we used a linear mixed-effects model (LMM) (for repeated measures), which is capable of handling unbalanced data (West, Welch, & Galecki, 2014), in all analyses involving visibility as a factor. Also, in all experiments, there were not enough trials with visibility ratings of 2 and 3 to allow meaningful analysis of each visibility level. We therefore combined trials on which visibility was rated 2 or 3 for the analyses. For analyses in which visibility was not a factor, we used repeated measures analysis of variance (ANOVA). All analyses (LMM and ANOVA) were calculated using SAS (version 9.4). Inferring that awareness is necessary for grouping to occur rely on null effects when the prime is reported invisible. To evaluate evidence in favor of the null hypothesis (which is not allowed in the classic significance tests), we used Bayesian statistics, using JASP statistical software (www.jasp-stats.org), and we report the evidence in favor of the null hypothesis, Bayes Factor BF_{01}, when applicable.

2.2. Results

Two participants were excluded from the analysis, one who gave visibility rating 3 on 21% of catch trials, and one who indicated visibility rating 2 on 79% of catch trials. Additional three participants were excluded as they did not experience suppression typical for CFS, reporting seeing a prime on 68%, 87%, and 93% of prime-present trials. For the remaining eighteen participants, 74% of all catch trials were rated with visibility rating 0 and only 4.51% with visibility rating 3.

Mean proportions of trials at each level of prime visibility as a function of SOA are presented in Fig. 2A. Across all SOAs, the prime was rated invisible on more than 50% of the trials (60%, 58%, 56%, and 56%, for SOA 200, 400, 600, and 800 ms, respectively); proportions of trials with almost visible (visibility rating 2) and fully visible prime (visibility rating 3) were relatively low. A repeated measures ANOVA with SOA as within-subject factor and visibility rating as the dependent variable indicates a significant effect of SOA, $F(3, 51) = 2.91$, $p = .0434$. Post-hoc Tukey HDS comparisons revealed a difference only between the shortest and longest SOA, with higher visibility for 800-ms than 200-ms SOA. As can be seen in Fig. 2A, this increase was due to a slight decrease in the proportion of trials with visibility rating 0 and a slight increase in the proportion of trials with visibility rating 1 and 3.

In all RT analyses, trials in which responses to the target were incorrect (4.09% of trials) were excluded from the analyses, and trials with RTs more than 2 SD from condition mean for each participant were trimmed (4.94% of correct trials). Mean RTs and accuracy for congruent and incongruent conditions in each visibility level for each SOA are presented in Table 1.

The RT data were submitted to a linear mixed-effects model for repeated measures with visibility (0, 1, 2 + 3), congruency (congruent, incongruent), and SOA (200, 400, 600, or 800) as within-subject factors. If awareness of the stimulus is essential for grouping to be accomplished, then a significant interaction between congruency and visibility is expected, such that congruency effects would be observed when the prime is reported visible, but not when it is reported invisible. Follow-up analyses test performance difference between the congruent and incongruent conditions at each visibility level.

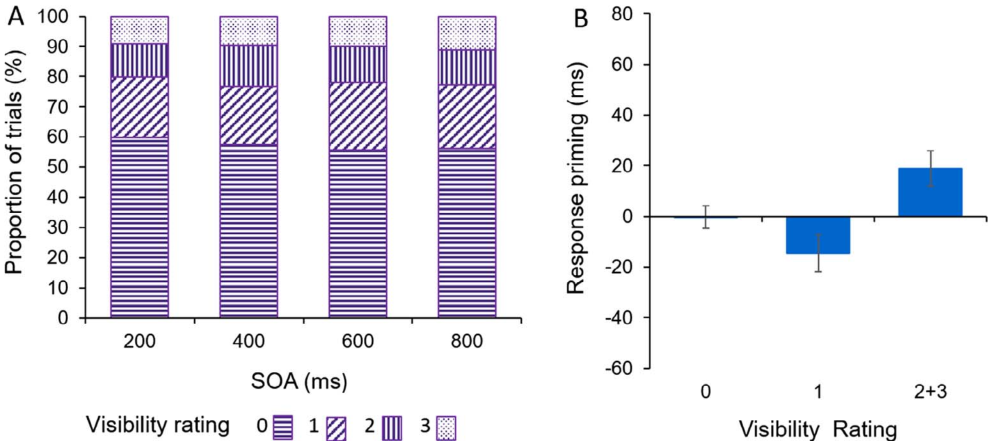

Fig. 2. Prime visibility ratings and response priming in Experiment 1. (A) Mean proportions of trials at each level of prime visibility as a function of prime-target SOA. (B) Mean response priming effects as a function of visibility rating. Error bars represent standard error.

Table 1

Mean RTs (in ms) and accuracy (in %) for congruent and incongruent conditions for each level of visibility in each SOA in Experiment 1. (Standard errors are in parentheses.)

	RT		Accuracy	
Visibility	Congruent	Incongruent	Congruent	Incongruent
SOA 200				
0	695 (29)	712 (29)	94 (0.03)	96 (0.03)
1	763 (30)	741 (30)	97 (0.03)	97 (0.03)
2	698 (32)	723 (32)	94 (0.03)	96 (0.03)
3	756 (33)	765 (32)	96 (0.03)	94 (0.03)
SOA 400				
0	692 (29)	681 (29)	93 (0.03)	95 (0.03)
1	746 (30)	709 (30)	99 (0.03)	97 (0.03)
2	703 (30)	709 (31)	95 (0.03)	94 (0.03)
3	659 (32)	704 (33)	95 (0.03)	93 (0.03)
SOA 600				
0	666 (29)	666 (29)	96 (0.03)	95 (0.03)
1	707 (30)	697 (30)	87 (0.03)	94 (0.03)
2	715 (32)	724 (31)	96 (0.03)	94 (0.03)
3	700 (32)	692 (32)	98 (0.03)	91 (0.03)
SOA 800				
0	665 (29)	659 (29)	96 (0.03)	94 (0.03)
1	688 (30)	700 (30)	93 (0.03)	97 (0.03)
2	679 (31)	758 (32)	98 (0.03)	95 (0.03)
3	672 (32)	657 (32)	91 (0.03)	99 (0.03)

The analysis of the RT data showed a significant effect of SOA, $F(3, 51) = 29.84$, $p < .0001$, indicating that RTs were faster as SOA increased. The main effect of visibility was also significant, $F(2, 24) = 30.2$, $p < .0001$, indicating that responses were faster on trials on which visibility was rated 0 than on the other trials, and this effect did not vary significantly with SOA, $F(6, 72) = 2.05$, $p = .0694$. The effect of congruency was not significant, $F(1, 17) = 0.15$, $p = 0.7056$, nor was the interaction between congruency and SOA, $F(3, 51) = 1.52$, $p = .2218$. Critically, the interaction between visibility and congruency was significant, $F(2, 24) = 5.47$, $p = .0111$, and this interaction effect did not vary significantly with SOA, $F(6, 70) = 1.67$, $p = .141$. Mean response priming effects for the three visibility conditions are presented in Fig. 2B. Follow-up analyses indicated, as can be seen in Fig. 2B, a significant response priming effect for visibility level 2 + 3, 19 ms, $F(1, 24) = 7.16$, $p = .0132$; there was no significant response priming effect for visibility level 0, $F < 1$, and no significant response priming effect, which tended to be negative, for visibility level 1, $F(1, 24) = 3.88$, $p = .0607$. To assess the null effect at visibility level 0, we used Bayesian paired-*t* test, which provided moderate support for the null hypothesis, Bayes Factor (BF_{01}) = 2.718.

Similar analysis was conducted on the accuracy data. They showed similar trends as the RT data, suggesting no speed-accuracy trade-off, but none of the main effects or interactions reached statistical significance.

The finding of no significant response priming effect when visibility was null is seen to suggest that grouping by luminance similarity does not take place when the stimulus is suppressed from awareness by CFS.

3. Experiment 2: Grouping by connectedness during CFS

This experiment is similar to Experiment 1, except that the grouping principle tested is connectedness.

3.1. Method

3.1.1. Participants

Nineteen individuals (18 right-handed, 12 females; age range = 20–30 years) participated in Experiment 2.

3.1.2. Apparatus, stimuli, procedure and design

The apparatus was the same as in Experiment 1. The prime consisted of a 4 × 4 circle elements connected by lines, subtending 3.69° × 3.69°, and forming columns or rows (see Fig. 1B). Each circle diameter subtended 0.45° and each line subtended 0.63° in length and 0.1° in width. The circles and lines were either all dark grey (RGB values 0, 0, 0; 0.09 cd/m^2) or all light grey (RGB values 190, 190, 190; 58.9 cd/m^2). The target subtended 3.8° × 3.8° and consisted of 4 vertical or horizontal lines, all of which were either dark (RGB values 10, 10, 10; 2.73 cd/m^2) or light (RGB values 225, 225, 225; 74.5 cd/m^2). Each line in the target was 3.8° in length and 0.4° in width.

The procedure and design were identical to those in Experiment 1 (Fig. 1).

3.2. Results

Two participants were excluded from the analysis, one who gave visibility rating 3 on 35% of catch trials, and one who reported seeing the prime on 99% of prime-present trials. For the remaining seventeen participants, 84.31% of all catch trials were rated with visibility rating 0 and only 1.10% with visibility rating 3.

Mean proportions of trials at each level of prime visibility as a function of SOA are presented in Fig. 3A. As in Experiment 1, the prime was largely invisible (visibility rating 0 on 62%, 60%, 59%, and 58% of prime-present trials, for SOA 200, 400, 600, and 800 ms, respectively). The ANOVA showed a significant effect of SOA, $F(3, 48) = 9.93$, $p < .0001$, and post hoc Tukey HDS comparisons revealed that visibility rating was significantly lower in the 200-ms SOA than in the longer SOAs, mainly due to an increase in the frequency of visibility 3 trials, and a slight decrease in the frequency of visibility 0 trials.

In all RT analyses, trials in which responses to the target were incorrect were excluded from the analysis (2.24% of trials). In addition, trials with RTs more than 2 SD from condition mean for each participant were trimmed (5.04% of correct trials). Mean RTs and accuracy for congruent and incongruent conditions in each level of visibility for each SOA are presented in Table 2.

The RT data were submitted to a linear mixed-effects model for repeated measures (Visibility × Congruency × SOA). The analysis revealed a significant effect of SOA, $F(3, 48) = 47.72$, $p < .0001$, indicating that responses were faster as SOA increased, and this effect was greater for higher levels of visibility, as indicated by the significant interaction between SOA and visibility, $F(6, 55) = 10.03$, $p < .0001$. Responses were faster on trials on which visibility was rated 0 than on the other trials, $F(2, 20) = 132.22$, $p < .0001$. Responses on congruent trials were faster than on incongruent trials, $F(1, 16) = 42.56$, $p > .0001$, and this difference did not interact significantly with SOA, $F(3, 48) = 1.92$, $p = .1385$. Importantly, there was a significant interaction between visibility and congruency, $F(2, 18) = 17.73$, $p < .0001$, which did not vary significantly with SOA, $F(6, 52) = 1.57$, $p = .1743$. Mean response priming effects for the three visibility conditions (0, 1, 2 + 3) are depicted in Fig. 3B. Follow-up analyses revealed, as can be seen in Fig. 3B, a significant response priming effect for visibility 1, 44 ms, $F(1, 18) = 17.95$, $p = .0005$, and a significant response priming effect for visibility 2 + 3, 45 ms, $F(1, 18) = 39.32$, $p < .0001$. No significant response priming effect was observed when visibility

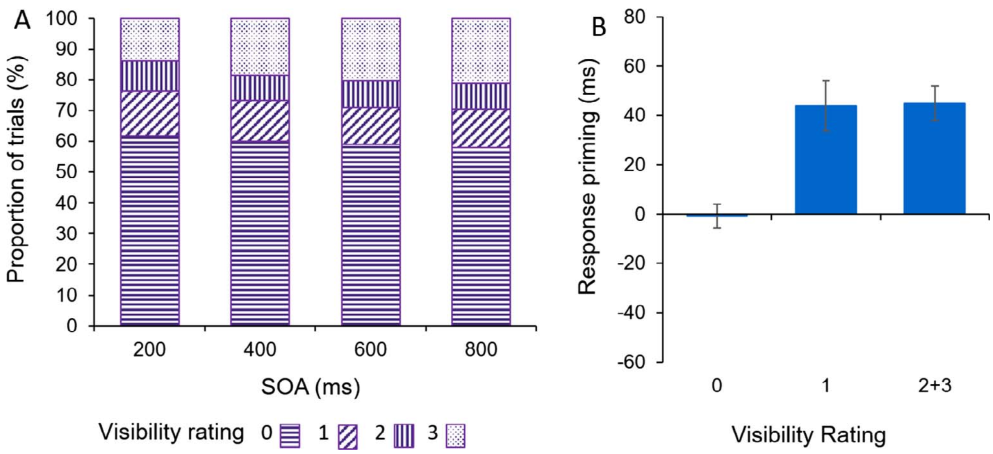

Fig. 3. Prime visibility ratings and response priming in Experiment 2. (A) Mean proportions of trials at each level of prime visibility as a function of prime-target SOA. (B) Mean response priming effects as a function of visibility rating. Error bars represent standard error.

Table 2
Mean RTs (in ms) and accuracy (in %) for congruent and incongruent conditions for each level of visibility in each SOA in Experiment 2. (Standard errors are in parentheses.)

Visibility	RT		Accuracy	
	Congruent	Incongruent	Congruent	Incongruent
SOA 200				
0	658 (36)	651 (36)	97 (0.02)	96 (0.02)
1	768 (38)	834 (38)	98 (0.02)	91 (0.02)
2	838 (40)	849 (39)	96 (0.03)	96 (0.02)
3	723 (38)	801 (38)	97 (0.02)	95 (0.02)
SOA 400				
0	637 (36)	624 (36)	97 (0.02)	97 (0.02)
1	760 (38)	782 (38)	95 (0.02)	98 (0.02)
2	744 (40)	769 (39)	97 (0.03)	99 (0.02)
3	678 (37)	737 (38)	97 (0.03)	94 (0.03)
SOA 600				
0	637 (36)	634 (36)	96 (0.02)	98 (0.02)
1	730 (39)	777 (38)	98 (0.02)	97 (0.02)
2	753 (40)	744 (40)	99 (0.02)	95 (0.03)
3	655 (37)	670 (37)	96 (0.03)	96 (0.02)
SOA 800				
0	610 (36)	631 (36)	97 (0.02)	96 (0.02)
1	710 (38)	749 (39)	94 (0.02)	98 (0.02)
2	742 (40)	743 (40)	97 (0.02)	97 (0.03)
3	617 (37)	705 (37)	97 (0.02)	94 (0.02)

was null, $F < 1$. Bayesian analysis provided moderate support for the null hypothesis, Bayes Factor (BF_{01}) = 3.237.

Similar analysis was conducted on the accuracy data. Accuracy data showed similar trends as the RT data, suggesting no speed-accuracy trade-off, but none of the main effects or interactions reached statistical significance.

The finding of no significant response priming effect when visibility was null, suggests that grouping by connectedness may not occur when the stimulus is rendered invisible by CFS.

In the present experiment, due to the specific stimuli used, the task-irrelevant color of the prime and the target, although not exactly identical, could be compatible or incompatible: prime and target could be both dark or both light (i.e., color compatibility) or prime could be dark and target light, and vice versa (i.e., color incompatibility). Therefore, we conducted an additional analysis using a linear mixed-effects model for repeated measures (Visibility × Congruency × Color Compatibility × SOA) on RTs and accuracy, to examine the effect of prime-target color compatibility on performance. The results for RTs showed no significant effect of prime-target color compatibility, $F < 1$. There was a significant interaction between color compatibility and visibility, $F(2, 20) = 5.80$, $p = .0103$, but none of the follow-up comparisons were statistically significant. No other interactions involving color compatibility were significant. Similar analysis conducted on the accuracy data showed no significant effect. Thus, these results show no effect of color compatibility on performance, suggesting no representation of the irrelevant color of the prime when the invisibility of the prime was induced by CFS.

4. Discussion: Experiments 1 and 2

The results of Experiments 1 and 2 show, across all prime-target SOAs, no significant response priming when visibility was null, and significant response priming when the prime was visible (visibility rating 2 + 3). These results suggest that no grouping by luminance similarity or by connectedness takes place when the stimulus is suppressed from awareness by CFS. The difference between the experiments with regard to visibility rating 1 – a significant response priming for connectedness but no significant response priming for luminance similarity (with a tendency for negative priming) – is not entirely clear; we return to this finding in the General discussion.

On the face of it, the results of Experiment 1 appear to be inconsistent with the findings of Montoro et al. (2014), which suggest that grouping by luminance similarity does occur in the absence of consciousness. However, Montoro et al. (2014) used sandwich masking, rather than CFS, to render the stimulus invisible. Previous research has provided evidence that processing during CFS is limited (e.g., Faivre & Koch, 2014; Moors et al., 2016; Stein & Sterzer, 2014). Thus, the discrepancy between our finding and the finding of Montoro et al. (2014) may be related to the different methods used to suppress the stimulus from awareness. In the next two experiments we examined the same grouping principles as the ones examined in Experiments 1 and 2, using sandwich masking to induce prime invisibility, in matched conditions: Primes and targets were identical to the comparable ones in Experiments 1 and 2, and the masks employed were such that the proportion of trials rated invisible was similar to their proportion under CFS.

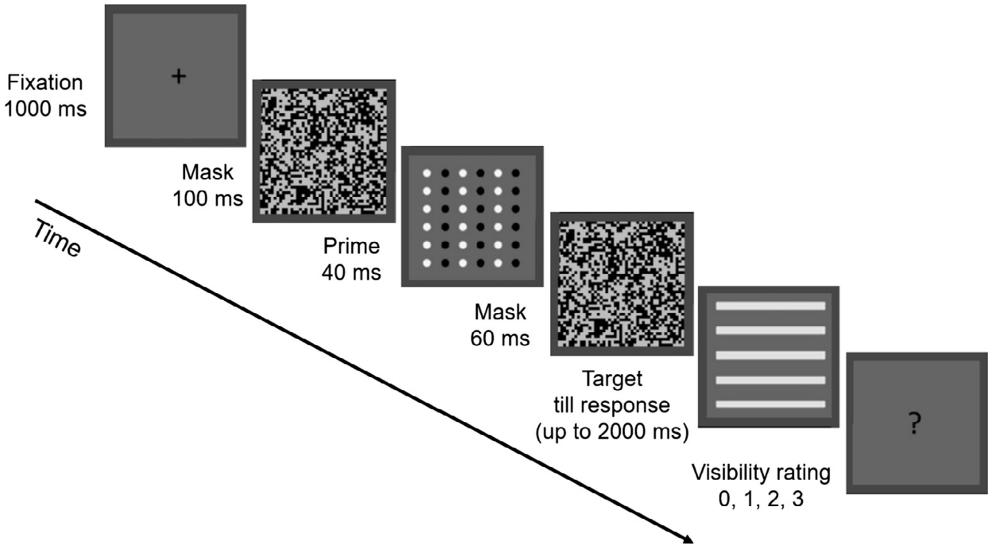

Fig. 4. The sequence of events in Experiments 3 and 4. Primes and targets in Experiment 3 were identical to those in Experiment 1, and primes and targets in Experiment 4 were identical to the ones in Experiment 2. The example depicts an incongruent trial in Experiment 3 (grouping by luminance similarity).

5. Experiment 3: Grouping by luminance similarity under visual masking

In this experiment we examined again whether grouping by luminance similarity can take place in the absence of visual awareness, with stimuli identical to the ones used in Experiment 1, but using sandwich masking to suppress the prime from awareness. This experiment is similar to the one by Montoro et al. (2014; Experiment 2), except that, as noted earlier, they used an objective measure of prime visibility, whereas we used a subjective measure of visibility on each trial.

5.1. Method

5.1.1. Participants

Twenty individuals (18 right-handed, 17 females; age range = 19–37 years) participated in Experiment 3.

5.1.2. Apparatus, stimuli, procedure and design

The apparatus was the same as in Experiments 1 and 2, except that no stereoscope was attached to the chin rest. Prime and target were identical to the ones in Experiment 1 (Fig. 1A and D). The forward and backward masks subtended $4.5^{\circ} \times 4.5^{\circ}$ and consisted of random noise patterns (Fig. 4). The elements of the noise patterns ($0.08^{\circ} \times 0.08^{\circ}$) were randomly placed, half of the elements were dark grey (RGB 30, 30, 30) and half of them were light grey (RGB 110, 110, 110). During the experiment, each particular mask was randomly chosen from a pool of 100 masks and appeared just once in a trial. Participants viewed the screen through a circular aperture (16 cm in diameter) of a matte black cardboard sheet.

The sequence of events in each trial is shown in Fig. 4. Each trial started with a fixation mark ($0.5^{\circ} \times 0.5^{\circ}$ black cross) 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. Response requirements to the target were the same as in Experiments 1 and 2. The response was followed by a question mark in the center of the screen, prompting the participants to provide subjective report of prime visibility, as in Experiments 1 and 2.

All the combinations of prime orientation, target orientation and target color were presented with equal frequency in a random fashion. Prime and target were equally likely to be congruent or incongruent in their orientation. Each participant completed 336 experimental trials, including 16 catch trials in which no prime was presented, divided into 4 blocks. The experimental trials were preceded by a practice block of 32 trials. During the practice, an auditory tone provided immediate feedback after an incorrect response or when 2000 ms had elapsed with no response.

5.2. Results

One participant, who gave visibility rating 2 on 62% of catch trials and never gave visibility rating 0, was excluded from the analyses. For the remaining nineteen participants, 77% of all catch trials were rated with visibility rating 0 and only 3.62% with visibility rating 3.

Mean proportions of trials at each level of prime visibility are presented in Fig. 5A The prime was largely invisible, with 67% of prime-present trials with visibility rating 0, and the frequency of trials with visible prime was low (7.8%).

In all RT analyses, trials in which responses to the target were incorrect were excluded from the analysis (2.25% of trials), as were

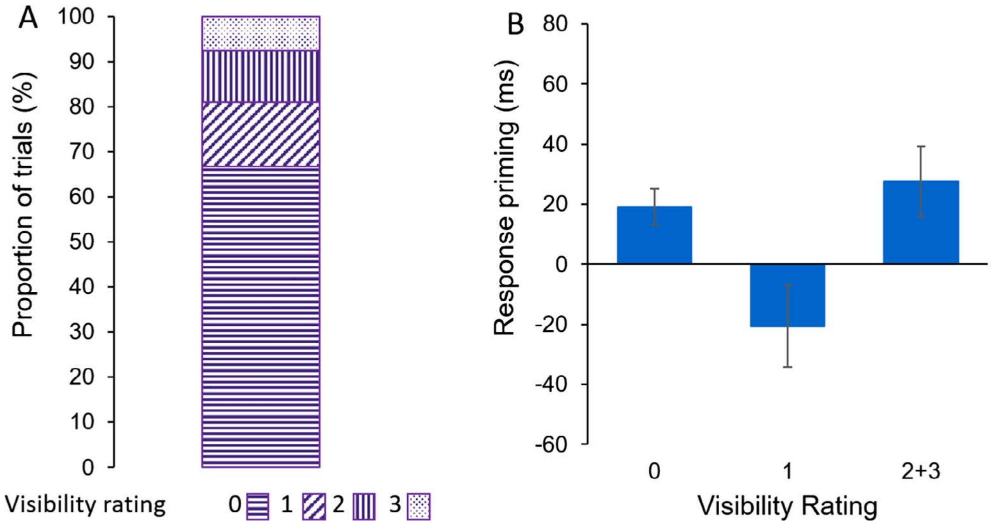

Fig. 5. Prime visibility ratings and response priming in Experiment 3. (A) Mean proportions of trials at each level of prime visibility. (B) Mean response priming effects as a function of visibility rating. Error bars represent standard error.

trials with RTs more than 2 SD from the condition mean for each participant (5.06% of correct trials). Mean RTs and accuracy for congruent and incongruent trials in each level of visibility are presented in Table 3.

The RT data were submitted to a linear mixed-effects model for repeated measures with visibility (0, 1, 2 + 3) and congruency (congruent, incongruent) as within-subject factors. The analysis revealed a significant effect of visibility, $F(2, 23) = 116.46$, $p < .0001$, indicating that RTs were the fastest when the prime was invisible. There was no significant effect of congruency, $F(1, 18) = 1.89$, $p = .1856$, but the interaction between visibility and congruency was significant, $F(2, 21) = 4.27$, $p = .0279$. Mean response priming effects as a function of level of visibility are depicted in Fig. 5B. Follow-up analyses revealed, as can be seen in Fig. 5B, a significant response priming effect for visibility 0, 19 ms, $F(1, 21) = 9.49$, $p = .0057$, and for visibility 2 + 3, 28 ms, $F(1, 21) = 5.53$, $p = .0285$; the difference in magnitude between these two response priming effects was not significant, $F < 1$. The negative priming observed for visibility 1 was not significant, $F(1, 21) = 2.33$, $p = .1417$.

Similar analysis conducted on the accuracy data showed no significant main effects or interactions.

Thus, the present results show significant response priming, and of similar magnitude, when the prime was reported invisible (visibility 0) and when it was reported visible (visibility 2 + 3). The former is in a clear contrast to the results of Experiment 1, in which no significant response priming was observed when visibility was null. The non-significant negative response priming effect for visibility rating 1 (Fig. 5B), which was observed also in Experiment 1 (Fig. 2B), is not entirely clear. We return to this finding in the General discussion.

6. Experiment 4: Grouping by connectedness under visual masking

This experiment is similar to Experiment 3, except that the grouping process tested is connectedness.

6.1. Method

6.1.1. Participants

Twenty-one individuals (19 right-handed, 16 females; age range 19–33 years) participated in Experiment 4.

6.1.2. Apparatus, stimuli, procedure and design

The apparatus was the same as in Experiment 3. Primes and targets were identical to the ones in Experiment 2. The masks were

Table 3
Mean RT (in ms) and accuracy (%) for congruent and incongruent conditions for each level of visibility in Experiment 3. (Standard errors are in parentheses.)

	RT		Accuracy	
Visibility	Congruent	Incongruent	Congruent	Incongruent
0	583 (33)	602 (33)	98 (0.01)	97 (0.01)
1	712 (34)	692 (34)	95 (0.02)	95 (0.02)
2	682 (34)	710 (34)	97 (0.02)	97 (0.02)
3	707 (35)	736 (35)	95 (0.02)	97 (0.02)

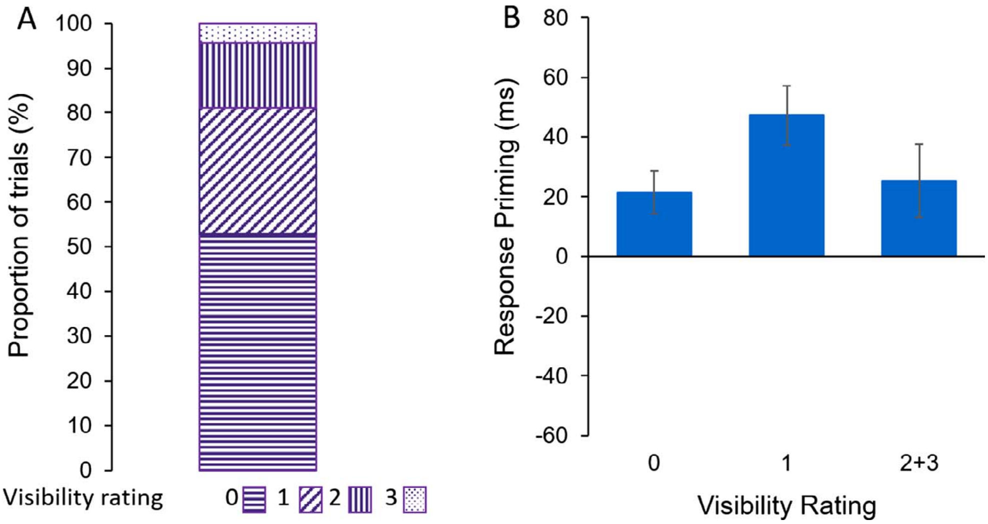

Fig. 6. Prime visibility ratings and response priming in Experiment 4. (A) Mean proportions of trials at each level of prime visibility. (B) Mean response priming effects as a function of visibility rating. Error bars represent standard error.

the same as in Experiment 3 except that the dark and light colors had RGB values of 0, 0, 0 and 190, 190, 190, respectively. All other aspects of the procedure and design were the same as in Experiment 3.

6.2. Results

One participant, who indicated visibility rating of 3 on 88% of catch trials, was excluded from the analyses. For the remaining twenty participants, 55% of all catch trials were rated with visibility rating 0 and only 2.50% with visibility rating 3.

Mean proportions of trials at each level of prime visibility are presented in Fig. 6A. The prime was largely invisible, with visibility rating of 0 on 53% of prime-present trials, and the frequency of trials with visibility rating of 3 was very low (4.31%).

In all RT analyses, trials in which responses to the target were incorrect were excluded from the analyses (3.23% of trials), as were trials in which RTs were more than 2 SD from condition mean for each participant (5.10% of correct trials). Mean RTs and accuracy for congruent and incongruent conditions in each level of visibility are presented in Table 4.

A linear mixed-effects model for repeated measures with visibility (0, 1, 2 + 3) and congruency (congruent, incongruent) as within-subject factors was used to analyze the RT data. The analysis revealed a significant effect of visibility, $F(2, 27) = 14.59$, $p < 0001$, indicating faster responses on trials with visibility rating 0 than on the other trials. Congruent trials were faster than incongruent trials, $F(1, 19) = 28.90$, $p < .0001$. The interaction between congruency and visibility was not significant, $F(2, 27) = 2.23$, $p = .1270$. Mean response priming effects as a function of visibility rating are depicted in Fig. 6B. Follow-up analyses revealed, as can be seen in Fig. 6B, a significant priming effects for visibility 0, 21 ms, $F(1, 27) = 8.53$, $p = .007$, and for visibility 1, 47 ms, $F(1, 27) = 22.31$, $p < .0001$; the priming effect for visibility 2 + 3 just approach significance, 25 ms, $F(1, 27) = 4.20$, $p = .0504$. Combining visibility rating 1, 2, and 3 as reflecting awareness of the prime, yields a significant response priming effect, 38 ms, $F(1, 15) = 23.73$, $p = .\ 0002$. There was no significant difference between the priming effect when visibility was null and when the prime was reported visible (2 + 3), $F < 1$.

Similar analysis conducted on the accuracy data showed no significant main effects or interactions.

As in Experiment 2, we examined the effect of prime-target color compatibility on performance. We conducted a linear mixed-effects analyses for repeated measures (Visibility × Congruency × Color Compatibility) on the RT and accuracy data. The analyses showed no significant effects of color compatibility, $Fs < 1$, and no significant interactions involving this factor, suggesting no effect of color compatibility, regardless of the visibility of the prime.

Table 4
Mean RT (ms) and accuracy (%) for congruent and incongruent conditions for each level of visibility in Experiment 4. (Standard errors are in parentheses.)

	RT		Accuracy	
Visibility	Congruent	Incongruent	Congruent	Incongruent
0	627 (25)	649 (25)	93 (0.03)	94 (0.03)
1	633 (25)	680 (25)	97 (0.04)	96 (0.04)
2	675 (26)	691 (26)	97 (0.03)	93 (0.04)
3	696 (30)	751 (31)	88 (0.04)	90 (0.04)

7. Discussion: Experiments 3 and 4

The results of Experiments 3 and 4, show, in a clear contrast to the results of Experiments 1 and 2, significant response priming both when visibility of the prime was null (visibility rating 0) and when the prime was reported visible (visibility rating 2 + 3). In each experiment, there was no significant difference between the magnitude of the response priming effect when the prime was invisible and when it was visible. Furthermore, the response priming effects in the two experiments were similar except for visibility rating 1. A comparison of the response priming effects of the two experiments by a linear mixed-effects model for repeated measures (Visibility × Congruency × Experiment) with experiment as a between-subjects factor, showed a significant interaction between experiment, congruency, and visibility, $F(2, 49) = 6.40$, $p = .0034$. Follow up analyses confirmed that the response priming effects for visibility ratings 0 and for visibility rating 2 + 3 were similar in the two experiments: Neither the effect of congruency when the prime was reported invisible (visibility rating 0), $F(1, 37) = 21.85$, $p < .0001$, nor the effect of congruency when the prime was reported visible (visibility rating 2 + 3), $F(1, 23) = 12.78$, $p = .0016$, interacted with experiment, $F\text{s} < 1$. A significant interaction between congruency and experiment was found only when prime visibility was rated 1, $F(1, 27) = 14.38$, $p = .0018$; a significant response priming effect was present for connectedness (Fig. 6B) but not for luminance similarity (with a tendency for negative priming) (Fig. 5B). As noted earlier, we return to this finding in the General discussion.

Overall, the results of Experiments 3 and 4 indicate that grouping elements by luminance similarity or by connectedness into a vertically/horizontally oriented pattern can take place when the stimulus is suppressed from awareness by sandwich masking. Our results of unconscious grouping by luminance similarity using sandwich masking, are in agreement with the results of Montoro et al. (2014).

8. Response priming for invisible primes: Comparison between Experiments 1–4

The results of the present experiments show significant response priming effect for invisible primes (visibility rating 0) when rendered invisible by sandwich masking (Experiments 3 and 4; Figs. 5B and 6B); when the primes were rendered invisible by CFS, no significant response priming effect was observed for invisible primes (Experiments 1 and 2; Figs. 2B and 3B). These results suggest that the presence/absence of a significant response priming effect for invisible primes depends on the method used to suppress the stimulus from awareness. To more directly examine this suggestion, we compared response priming effects when visibility was null between the four experiments. To this end, a linear mixed-effects analysis for repeated measures with congruency (congruent, incongruent) as within-subject factor, and suppression method (CFS, masking), and grouping principle (color similarity, connectedness) as between-subject factors, was conducted on RTs for visibility level 0. The analysis yielded a significant interaction between suppression method and congruency, $F(1, 69) = 17.24$, $p < .0001$, which did not vary with grouping principle, $F < 1$. These results indicate that independently of grouping principle, the response priming effect (averaged 20.64 ms, $F(1, 37) = 21.85$, $p < .0001$, for sandwich masking; averaged 0.40 ms, $F < 1$, for CFS) differed significantly between the two suppression methods. This result supports the claim that the presence/absence of response priming for invisible primes depends on the method used render the stimulus invisible.

9. General discussion

In this study, we examined whether two basic grouping processes – grouping by luminance similarity and grouping by connectedness – can take place in the absence of visual awareness, using a priming paradigm and two methods to render the prime invisible, CFS and sandwich masking under matched conditions. Awareness of the prime was assessed using a trial-by-trial sensitive visibility rating scale (0–3), and unconscious grouping was measured as performance difference between prime-target congruent and incongruent conditions when the prime awareness was null (i.e., when prime visibility was rated 0).

The results show that grouping by luminance similarity and by connectedness can occur in the absence of visual awareness, depending on the level at which the suppression induced by the method used to render the stimulus invisible takes place. No evidence for unconscious grouping by luminance similarity or by element connectedness was found during CFS (Experiments 1 and 2). In both experiments, and across all prime-target SOAs, there were no response priming effects when the prime was reported invisible (visibility rating 0). Significant response priming effects were observed when the prime was reported visible (visibility rating 2 + 3). In contrast, a clear evidence for unconscious grouping by luminance similarity and by connectedness was found when sandwich masking was used to render the prime invisible (Experiments 3 and 4). For both grouping processes, significant response priming effects of similar magnitude were observed when the prime was reported visible and when the prime was reported invisible, suggesting not only that these grouping processes can occur without visual consciousness, but also that they do not benefit from it.

9.1. Suppression methods

One implication of the present results concerns the methods used to suppress stimuli from awareness. Our finding of unconscious grouping with sandwich masking and its absence during CFS is consistent with previous findings demonstrating limited unconscious processing with CFS in comparison to visual masking (e.g., Almeida, Pajtas, Mahon, Nakayama, & Caramazza, 2013; Izatt, Dubois, Faivre, & Koch, 2014; Peremen & Lamy, 2014a). For example, Peremen and Lamy (2014a) found priming for directional arrows with metacontrast masking, but no priming was obtained with CFS. Almeida et al. (2013) found priming for both happy and angry facial expressions under backward masking, but only for angry facial expression when CFS was used. Izatt et al. (2014), who compared face processing with CFS and sandwich masking, found that both repetition and identity priming were qualitatively stronger under masking than under interocular suppression. In addition, in separate experiments, evidence for unconscious formation of subjective contours was found with metacontrast masking (Poscoliero et al., 2013) but not with CFS (Harris et al., 2011), and Hesselmann, Darcy, Sterzer and Knops (2015) showed that numerical priming, which has been shown for backward masking (Koechlin, Naccache, Block, & Dehaene, 1999) is limited under CFS. These and other psychophysical findings (see Breitmeyer, 2015, for a review) are supported by neural findings indicating that the neural activity of stimuli suppressed by CFS is limited to early visual areas (e.g., Hesselmann & Malach, 2011; Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014; Yuval-Greenberg & Heeger, 2013). Thus, there is converging evidence that processing during CFS is limited and confines to early visual areas (see also, Moors, Hesselmann, Wagemans, & van Ee, 2017).

The idea that the suppression induced by different methods used to render a stimulus inaccessible to visual awareness can occur at different levels, as the present results suggest regarding CFS versus masking, is in agreement with Breitmeyer's (2015) proposal of a functional hierarchy of unconscious visual processing, as indexed by different psychophysical suppression methods. According to Breitmeyer, unconscious processing indexed by binocular rivalry suppression is at the lowest level of this hierarchy, whereas unconscious processing indexed by object-substitution masking is at the highest level, and unconscious processing indexed by other methods can be mapped into the hierarchy at midrange levels. Breitmeyer further noted that the functional hierarchy is still tentative and subject to additions and revisions, and importantly, it does not map readily onto cortical anatomical levels.

9.2. Grouping processes

A second, not unrelated implication of our findings concerns the process of grouping itself. Similar to our finding with sandwich masking, grouping in the absence of awareness was found with methods other than CFS (Mitroff & Scholl, 2005; Montoro et al., 2014; Poscoliero et al., 2013). For example, Mitroff and Scholl (2005) showed that good continuation, proximity, connectedness, and common region can take place during motion-induced blindness, and Montoro et al. (2014) found unconscious priming for grouping by luminance similarity and by proximity with sandwich masking. If CFS indeed reduces or even block the flow of visual input to higher visual areas beyond V1 and V2 (e.g., Yuval-Greenberg & Heeger, 2013), the findings of unconscious grouping with visual masking but not with CFS are seen to suggest that grouping may occur at, or depends on feedback from, higher visual areas.

9.3. Additional results

This study yielded three additional results worth discussing.

Response priming for visibility rating 1. A puzzling difference was observed between the two grouping principles, which otherwise showed similar results in pattern and in magnitude, when visibility was rated 1: A significant response priming was observed for connectedness (Figs. 3B and 6B), but no significant priming effect was observed for luminance similarity, if anything, there was a non-significant negative priming (Figs. 2B and 5B). How can this result be explained? We can only speculate. Notwithstanding that the negative priming was not significant, it is reminiscent of the negative compatibility effect (NCE), which was observed with barely visible primes (e.g., Klapp & Hinkley, 2002). Klapp & Hinkley (2002) attribute this effect to a competition between inhibitory unconscious processes and excitatory conscious processes, whereas Lleras and Enns (2004) attribute it to the updating of perceptual objects, predicting that the effect should only be observed when the mask is relevant to the target identification task. Inconsistent with Lleras and Enns (2004) proposal, the negative priming was observed with different masks (CFS in Experiment 1, and sandwich masking in Experiment 3), none of which appeared to be task relevant. The inhibitory unconscious processes proposed by Klapp & Hinkley (2002) may be a better candidate, but it cannot easily account for the finding that the negative priming was observed for grouping by luminance similarity, but not by element connectedness. Possibly, although both are basic groupings, which exhibit similar time course (Rashal, Yeshurun, & Kimchi, 2017b), grouping by luminance similarity may be somewhat more difficult than grouping by connectedness. Consequently, uncertainty about the barely visible prime (visibility rating of 1) may have been greater for the former than for the latter, presumably leading, on some of the similarity trials, to inhibition of the primed response, which slowed RT for compatible trials relative to the non-compatible trials (e.g., Klapp & Hinkley, 2002). As noted, this explanation is highly speculative, and understanding this finding awaits further research.

Fastest RTs when visibility was null. In all four experiments, overall RTs were the fastest when the prime was invisible (i.e., visibility rating 0). Similar results were reported by Lamy and colleagues (Lamy, Alon, Carmel, & Shalev, 2015; Lamy, Carmel, & Peremen, 2017; Peremen & Lamy, 2014a), suggesting a possible cost of awareness. Presumably, awareness of an object interferes with the processing of a subsequent salient object that appears in a close temporal proximity. This is reminiscent of the phenomenon of attentional blink, in which the second of two targets cannot be detected when it appears close in time to the first, and is taken to reflect temporal costs in allocating selective attention. The present finding raises the question whether attentional blink is indeed due to attentional limitation, or rather to limitation of consciousness. This issue is worthy of further research.

Task relevance in unconscious processing. In the experiments testing for unconscious processing of grouping by connectedness (Experiments 2 and 4), there was, in addition to the congruency between the prime and target in task-relevant orientation, a potential congruency in task-irrelevant color: both prime and target could be dark or both could be light (color congruency) or one of them could be light and the other dark (color incongruency). Color is considered a low level feature that can even escape CFS (Hong & Blake, 2009). Nonetheless, there was no effect of color congruency when visibility was null with CFS, nor with sandwich masking, in which a clear congruency effect for orientation was observed. That is, a task-relevant feature (i.e., orientation) affected performance, but a task-irrelevant feature (i.e., color) did not, even when unconscious, demonstrating that task relevance plays a role in unconscious processing (van Gaal, de Lange, & Cohen, 2012). Similar findings were reported by Tapia, Breitmeyer, and Shooner (2010), who showed that a task-relevant feature, such as color or form, can be selectively attended, and a task-irrelevant feature can be "attentionally filtered out", during unconscious processing. The relationship between attention and consciousness has been a matter of a lively debate in the last two decades (e.g., Cohen, Cavanagh, Chun, & Nakayama, 2012), but it is beyond the scope of this paper. Nonetheless, our result, together with other findings reported in the literature (e.g., Kentridge, Nijboer, & Heywood, 2008; Tapia et al., 2010), are seen to support the claim about the possibility of attention without awareness, suggesting that attention is not sufficient for consciousness.

9.4. Methodological considerations

A concern for any attempt to examine unconscious processing is whether the stimuli of interest are indeed out of awareness. Unawareness can be assessed using a subjective measure, which is based on reports of subjective experience, e.g., on a 4-point visibility scale such as PAS, or using an objective measure, which is based on forced-choice discrimination performance. In this study, we used only a subjective measure of awareness (akin to PAS). The subjective measure has been criticized because of criterion bias. In the context of our study, one may argue that participants used the visibility scale differently when the prime was suppressed by CFS and when it was suppressed by masking, and this difference may account, at least partially, for the difference observed between the two suppression methods. Although this cannot be ruled out completely, there are reasons to doubt it. First, our results, suggesting limited unconscious processing during CFS in comparison to masking, agree with other results reported in the literature, some of which used an objective measure (e.g., Almeida et al., 2013). Second, and most importantly, as noted in the Introduction, there is evidence that subjective reports of conscious perception can be as sensitive as measures relying on objective discrimination performance, provided that the subjective measure employed is not dichotomous (e.g., Lamy et al., 2017; Peremen & Lamy, 2014b; Ramsøy & Overgaard, 2004). This evidence, along with the fact that subjective measures, unlike the objective ones, allow monitoring of consciousness trial by trials, support the use of a sensitive subjective measure.

10. Concluding remarks

In summary, our results demonstrate that grouping by luminance similarity and by connectedness can be accomplished in the absence of awareness when the stimulus is suppressed from awareness by visual masking. No indication for unconscious grouping was obtained with CFS. These results converge with other findings showing that certain perceptual organization processes can occur without visual awareness (e.g., Montoro et al., 2014; Poscoliero et al., 2013). These results also contribute to the converging evidence that processing during CFS is rather limited, and suggest the involvement of higher visual areas in perceptual organization (e.g., Lamme, 2015; Moors et al., 2016). Furthermore, these results demonstrate that whether a process can occur without awareness is dependent on the level at which the suppression induced by the method used to render the stimulus inaccessible to visual awareness takes place. Taken together, the present and previous results reported in the literature indicate that elucidating the nature of the suppression methods is crucial for understanding unconscious processing.

Acknowledgements

This research was supported by the Israel Science Foundation (ISF) (grant number 1473/15) to Ruth Kimchi. Facilities for conducting the research were provided by the Institute of Information Processing and Decision Making and by the Max Wertheimer Minerva Center for Cognitive Processes and Human Performance, University of Haifa. We report all data exclusions, manipulations, and measures, and how we determined our sample sizes. We are grateful to Guido Hesselmann and an anonymous reviewer for their helpful comments on a previous version of this article. Thanks to Mor Leder for her help in running the experiments.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.concog.2018.02.009.

References

Alais, D., Blake, R., & Lee, S. H. (1998). Visual features that vary together over time group together over space. *Nature Neuroscience, 1*(2), 160–164.

Almeida, J., Pajtas, P. E., Mahon, B. Z., Nakayama, K., & Caramazza, A. (2013). Affect of the unconscious: Visually suppressed angry faces modulate our decisions. *Cognitive, Affective, & Behavioral Neuroscience, 13*(1), 94–101. http://dx.doi.org/10.3758/s13415-012-0133-7.

Banica, T., & Schwarzkopf, D. S. (2016). Induction of Kanizsa contours requires awareness of the inducing context. *Plos One, 11*(8), e0161177. http://dx.doi.org/10.1371/journal.pone.0161177.

Behrmann, M., & Kimchi, R. (2003). What does visual agnosia tell us about perceptual organization and its relationship to object perception? *Journal of Experimental Psychology: Human Perception and Performance, 29*(1), 19–42. http://dx.doi.org/10.1037/0096-1523.29.1.19.

Breitmeyer, B. G. (2015). Psychophysical 'blinding' methods reveal a functional hierarchy of unconscious visual processing. *Consciousness and Cognition: An International Journal, 35*. http://dx.doi.org/10.1016/j.concog.2015.01.012.

Cohen, M. A., Cavanagh, P., Chun, M. M., & Nakayama, K. (2012). The attentional requirements of consciousness. *Trends in Cognitive Sciences, 16*(8), 411–417. http://dx.doi.org/10.1016/j.tics.2012.06.013.

Faivre, N., Berthet, V., & Kouider, S. (2012). Nonconscious influences from emotional faces: A comparison of visual crowding, masking, and continuous flash suppression. *Frontiers in Psychology, 3*, 129. http://dx.doi.org/10.3389/fpsyg.2012.00129.

Faivre, N., & Koch, C. (2014). Inferring the direction of implied motion depends on visual awareness. *Journal of Vision, 14*(4), http://dx.doi.org/10.1167/14.4.4.

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

Ghodrati, M., Morris, A. P., & Price, N. S. (2015). The (un)suitability of modern liquid crystal displays (LCDs) for vision research. *Frontiers in Psychology, 6*, 303. http://dx.doi.org/10.3389/fpsyg.2015.00303.

Gillebert, C. R., & Humphreys, G. W. (2015). Mutual interplay between perceptual organization and attention: A neuropsychological perspective. In J. Wagemans (Ed.). *The Oxford handbook of perceptual organisation*. Oxford University Press.

Hadad, B.-S., & Kimchi, R. (2008). Time course of grouping of shape by perceptual closure: Effects of spatial proximity and collinearity. *Perception & Psychophysics, 70*(5), 818–827. http://dx.doi.org/10.3758/pp.70.5.818.

Hadad, B.-S., Maurer, D., & Lewis, T. L. (2010). The development of contour interpolation: Evidence from subjective contours. *Journal of Experimental Child Psychology, 106*(2–3), http://dx.doi.org/10.1016/j.jecp.2010.02.003.

Harris, J. J., Schwarzkopf, D. S., Song, C., Bahrami, B., & Rees, G. (2011). Contextual illusions reveal the limit of unconscious visual processing. *Psychological Science, 22*(3), http://dx.doi.org/10.1177/0956797611399293.

Hesselmann, G., Darcy, N., Sterzer, P., & Knops, A. (2015). Exploring the boundary conditions of unconscious numerical priming effects with continuous flash suppression. *Consciousness and Cognition, 31*, 60–72. http://dx.doi.org/10.1016/j.concog.2014.10.009.

Hesselmann, G., & Malach, R. (2011). The link between fMRI-BOLD activation and perceptual awareness is “stream-invariant” in the human visual system. *Cerebral Cortex, 21*(12), 2829–2837. http://dx.doi.org/10.1093/cercor/bhr085.

Hong, S. W., & Blake, R. (2009). Interocular suppression differentially affects achromatic and chromatic mechanisms. *Attention, Perception, & Psychophysics, 71*(2), http://dx.doi.org/10.3758/app.71.2.403.

Izatt, G., Dubois, J., Faivre, N., & Koch, C. (2014). A direct comparison of unconscious face processing under masking and interocular suppression. *Frontiers in Psychology, 5*, 659. http://dx.doi.org/10.3389/fpsyg.2014.00659.

Jimenez, M., Montoro, P. R., & Luna, D. (2017). Global shape integration and illusory form perception in the absence of awareness. *Consciousness and Cognition, 53*, 31–46. http://dx.doi.org/10.1016/j.concog.2017.05.004.

Julesz, B. (1960). Binocular depth perception and pattern recognition. *Journal of the Optical Society of America, Program Supplement*.

Kentridge, R. W., Nijboer, T. C. W., & Heywood, C. A. (2008). Attended but unseen: Visual attention is not sufficient for visual awareness. *Neuropsychologia, 46*(3), 864–869. http://dx.doi.org/10.1016/j.neuropsychologia.2007.11.036.

Kimchi, R. (1998). Uniform connectedness and grouping in the perceptual organization of hierarchical patterns. *Journal of Experimental Psychology: Human Perception and Performance, 24*(4), 1105–1118. http://dx.doi.org/10.1037/0096-1523.24.4.1105.

Kimchi, R. (2000). The perceptual organization of visual objects: A microgenetic analysis. *Vision Research, 40*(10–12), 1333–1347. http://dx.doi.org/10.1016/s0042-6989(00)00027-4.

Kimchi, R. (2003). Visual perceptual organization: A microgenetic analysis. In R. Kimchi, M. Behrmann, & C. R. Olson (Eds.). *Perceptual organization in vision: Behavioral and neural perspectives*Mahwah, NJ: Lawrence Erlbaum Associates Publishers (pp. 117–154, xii, 475).

Kimchi, R. (2009). Perceptual organization and visual attention. *Progress in Brain Research, 176*, 15–33. http://dx.doi.org/10.1016/S0079-6123(09)17602-1.

Kimchi, R. (2012). Ontogenesis and microgenesis of visual perceptual organization. In J. A. Burack, J. T. Enns, & N. A. Fox (Eds.). *Cognitive neuroscience, development, and psychopathology: Typical and atypical developmental trajectories of attention*New York, NY: Oxford University Press (pp. 101–131, x, 320).

Kimchi, R., Hadad, B.-S., Behrmann, M., & Palmer, S. E. (2005). Microgenesis and ontogenesis of perceptual organization: Evidence from global and local processing of hierarchical patterns. *Psychological Science, 16*(4), 282–290. http://dx.doi.org/10.1111/j.0956-7976.2005.01529.x.

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

Klapp, S. T., & Hinkley, L. B. (2002). The negative compatibility effect: Unconscious inhibition influences reaction time and response selection. *Journal of Experimental Psychology: General, 131*(2), http://dx.doi.org/10.1037/0096-3445.131.2.255.

Koechlin, E., Naccache, L., Block, E., & Dehaene, S. (1999). Primed numbers: Exploring the modularity of numerical representations with masked and unmasked semantic priming. *Journal of Experimental Psychology-Human Perception and Performance, 25*(6), 1882–1905. http://dx.doi.org/10.1037/0096-1523.25.6.1882.

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

Lagroix, H. E., Yanko, M. R., & Spalek, T. M. (2012). LCDs are better: Psychophysical and photometric estimates of the temporal characteristics of CRT and LCD monitors. *Attention, Perception, & Psychophysics, 74*(5), 1033–1041. http://dx.doi.org/10.3758/s13414-012-0281-4.

Lamme, V. A. F. (2015). The crack of dawn—Perceptual functions and neural mechanisms that mark the transition from unconscious processing to conscious vision. In T. Metzinger, & J. M. Windt (Eds.). *Open MIND: 22(T)*. Frankfurt am Main: MIND Group.

Lamy, D., Alon, L., Carmel, T., & Shalev, N. (2015). The role of conscious perception in attentional capture and object-file updating. *Psychological Science, 26*(1), 48–57. http://dx.doi.org/10.1177/0956797614556777.

Lamy, D., Carmel, T., & Peremen, Z. (2017). Prior conscious experience enhances conscious perception but does not affect response priming. *Cognition, 160*, 62–81. http://dx.doi.org/10.1016/j.cognition.2016.12.009.

Lau, J. S., & Cheung, S. H. (2012). Illusory contour formation survives crowding. *Journal of Vision, 12*(6), 15. http://dx.doi.org/10.1167/12.6.15.

Lleras, A., & Enns, J. T. (2004). Negative compatibility or object updating? A cautionary tale of mask-dependent priming. *Journal of Experimental Psychology: General, 133*(4), 475–493. http://dx.doi.org/10.1037/0096-3445.133.4.475.

Mack, A., Tang, B., Tuma, R., & Kahn, S. (1992). Perceptual organization and attention. *Cognitive Psychology, 24*(4), 475–501.

Mitroff, S. R., & Scholl, B. J. (2005). Forming and updating object representations without awareness: Evidence from motion-induced blindness. *Vision Research, 45*(8), 961–967. http://dx.doi.org/10.1016/j.visres.2004.09.044.

Montoro, P. R., Luna, D., & Ortells, J. J. (2014). Subliminal Gestalt grouping: Evidence of perceptual grouping by proximity and similarity in absence of conscious perception. *Consciousness and Cognition, 25*, 1–8. http://dx.doi.org/10.1016/j.concog.2014.01.004.

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

Moors, P., Hesselmann, G., Wagemans, J., & van Ee, R. (2017). Continuous flash suppression: Stimulus fractionation rather than integration. *Trends in Cognitive Sciences, 21*(10), 719–721. http://dx.doi.org/10.1016/j.tics.2017.06.005.

Moors, P., Wagemans, J., van Ee, R., & de-Wit, L. (2016). No evidence for surface organization in Kanizsa configurations during continuous flash suppression. *Attention, Perception, & Psychophysics, 78*(3), 902–914. http://dx.doi.org/10.3758/s13414-015-1043-x.

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

Palmer, S. E., Brooks, J. L., & Nelson, R. (2003). When does grouping happen? *Acta Psychologica, 114*, 311–330.

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

Peremen, Z., & Lamy, D. (2014b). Do conscious perception and unconscious processing rely on independent mechanisms? A meta-contrast study. *Consciousness and Cognition, 24*, 22–32.

Peremen, Z., & Lamy, D. (2014a). Comparing unconscious processing during continuous flash suppression and meta-contrast masking just under the limen of consciousness. *Frontiers in Psychology, 5*. http://dx.doi.org/10.3389/fpsyg.2014.00969 ARTN 969.

Peterson, M. A., & Kimchi, R. (2013). Perceptual organization in vision. In D. Reisberg (Ed.). *Oxford library of psychology*New York, NY: Oxford University Press (pp. 9–31, xx, 1076).

Poscoliero, T., Marzi, C. A., & Girelli, M. (2013). Unconscious priming by illusory figures: The role of the salient region. *Journal of Vision, 13*(5).

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

Quinn, P. C., & Bhatt, R. S. (2015). Development of perceptual organization in infancy. In J. Wagemans (Ed.). *The Oxford handbook of perceptual organization*. Oxford, UK: Oxford University Press.

Ramsøy, T. Z., & Overgaard, M. (2004). Introspection and subliminal perception. *Phenomenology and the Cognitive Sciences, 3*, 1–23.

Rashal, E., Yeshurun, Y., & Kimchi, R. (2017b). The time course of the competition between grouping organizations. *Journal of Experimental Psychology: Human Perception and Performance, 43*(3), 608–618. http://dx.doi.org/10.1037/xhp0000334.

Rashal, E., Yeshurun, Y., & Kimchi, R. (2017a). Attentional requirements in perceptual grouping depend on the processes involved in the organization. *Attention, Perception, & Psychophysics, 79*, 2073–2087. http://dx.doi.org/10.3758/s13414-017-1365-y.

Razpurker-Apfeld, I., & Kimchi, R. (2007). The time course of perceptual grouping: The role of segregation and shape formation. *Perception & Psychophysics, 69*(5), 732–743. http://dx.doi.org/10.3758/bf03193775.

Schwarzkopf, D. S., & Rees, G. (2011). Interpreting local visual features as a global shape requires awareness. *Proceedings of the Royal Society B – Biological Sciences, 278*(1715), 2207–2215.

Sekuler, A. B., & Bennett, P. J. (2001). Generalized common fate: Grouping by common luminance changes. *Psychological Science, 12*(6), http://dx.doi.org/10.1111/1467-9280.00382.

Sobel, K. V., & Blake, R. (2003). Subjective contours and binocular rivalry suppression. *Vision Research, 43*(14), 1533–1540.

Stein, T., & Sterzer, P. (2014). Unconscious processing under interocular suppression: Getting the right measure. *Frontiers in Psychology, 5*.

Sterzer, P., Stein, T., Ludwig, K., Rothkirch, M., & Hesselmann, G. (2014). Neural processing of visual information under interocular suppression: A critical review. *Frontiers in Psychology, 5*, 453. http://dx.doi.org/10.3389/fpsyg.2014.00453.

Sweeny, T. D., Grabowecky, M., & Suzuki, S. (2011). Awareness becomes necessary between adaptive pattern coding of open and closed curvatures. *Psychological Science, 22*(7), 943–950. http://dx.doi.org/10.1177/0956797611413292.

Tapia, E., Breitmeyer, B. G., & Shooner, C. R. (2010). Role of task-directed attention in nonconscious and conscious response priming by form and color. *Journal of Experimental Psychology: Human Perception and Performance, 36*(1), 74–87. http://dx.doi.org/10.1037/a0017166.

Tsuchiya, N., & Koch, C. (2005). Continuous flash suppression: Strong dichoptic masking can reduces negative afterimage. *Journal of Cognitive Neuroscience,* 53–153.

van Gaal, S., de Lange, F. P., & Cohen, M. X. (2012). The role of consciousness in cognitive control and decision making. *Frontiers in Human Neuroscience, 6*, 121. http://dx.doi.org/10.3389/fnhum.2012.00121.

Wagemans, J., Elder, J. H., Kubovy, M., Palmer, S. E., Peterson, M. A., Singh, M., & von der Heydt, R. (2012). A century of Gestalt psychology in visual perception: I. Perceptual grouping and figure-ground organization. *Psychological Bulletin, 138*(6), 1172–1217. http://dx.doi.org/10.1037/a0029333.

Wang, L., Weng, X., & He, S. (2012). Perceptual grouping without awareness: Superiority of Kanizsa triangle in breaking interocular suppression. *Plos One, 7*(6), e40106. http://dx.doi.org/10.1371/journal.pone.0040106.

Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt, II. [Investigations in Gestalt Theory: II. Laws of organization in perceptual forms]. *Psychologische Forschung, 4*, 301–350.

West, B. T., Welch, K. B., & Galecki, A. T. (2014). *Linear mixed models: A practical guide using statistical software* (2nd ed.). NY: CRC Press.

Yuval-Greenberg, S., & Heeger, D. J. (2013). Continuous flash suppression modulates cortical activity in early visual cortex. *Journal of Neuroscience, 33*(23), 9635–9643. http://dx.doi.org/10.1523/JNEUROSCI.4612-12.2013.