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REGISTERED REPORTS AND REPLICATIONS

Visual search of illusory contours: The role of illusory contour clarity

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Abstract

Kanizsa-type illusory contours demonstrate an important function of the visual system—object inference from incomplete boundaries, which can be due to low luminance environments, camouflage, or occlusion. At a perceptual level, Kanizsa figures have been shown to have various degrees of clarity, depending on the features of the inducers. The aim of the present study is to evaluate whether contour clarity influences search efficiency of Kanizsa-type illusory contours. Experiment 1 will examine search for a Kanizsa-type illusory target among Kanizsa-type illusory distractors, by manipulating contour clarity using inducer size in three conditions, compared with search for a nonillusory perceptually grouped target among nonillusory perceptually grouped distractors with manipulated inducer size. Experiment 2 will address the effects of contour clarity on visual search by manipulating the number of arcs (i.e., line ends) comprising the inducers, in a visual search task of Kanizsa-type stimuli, compared with visual search for nonillusory grouped targets and distractors when the number of arcs are manipulated. To examine whether surface alterations had an impact on search in Experiment 1 due to changes in inducer size, Experiment 3 will examine search for Kanizsa stimuli formed from "smoothed" inducers, in comparison to search for Kanizsa stimuli used in Experiment 1. Together, these experiments will demonstrate whether contour clarity impacts visual search of illusory contours.

Keywords Visual search · Attention · Illusory contours · Kanizsa figures · Perceptual grouping

Illusory contours are special stimuli configurations evoking the percept of a geometric shape on top of partly occluded disks, despite the absence of any physical boundaries. The most famous example of an illusory contour is the Kanizsa triangle (Kanizsa, 1955). Illusory contours are useful stimuli for understanding how objects with partially visible edges, which can be a result of low luminance or occlusion, are constructed, recognized, and interpreted in the real world. Thus, illusory contours such as Kanizsa figures demonstrate an ecologically important visual function. Given their special configuration, changes in perceptual factors such as clarity of the illusory contour may also interact and interfere with attentional processes.

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Illusory contour perception clarity

Not all illusory configurations are equally perceived. Shipley and Kellman (1992) have proposed that the support ratio (i.e., the ratio of length of the luminance-specified contour to the length of the entire edge) affects the perceived clarity of illusory figures. Larger inducers and their closer spacing produce a stronger illusory edge, while smaller inducers and a greater separation between them produces a weaker illusory edge. This suggests that clarity depends on the ratio of inducing edge length to the extent of separation. In Shipley and Kellman's model, contour salience is a monotonically increasing function of the support ratio of inducer size and spacing. In Grossberg and Mingolla's (1985a, 1985b, 1987) approach, the primary determinant of contour formation is line ends or spatial discontinuities, such as the corners of a Kanizsa figure. Based on this approach, Lesher and Mingolla (1993) have shown that when inducers are composed of concentric circles with missing arcs, varying their number and thickness impacts the clarity and brightness of the illusory figures (Lesher & Mingolla, 1993). The degree of clarity and brightness of the illusory figure is an inverted U function of the number of arcs so that there is an optimal number of arcs for perceived clarity.

Visual search of illusory contours

Visual search studies with illusory contours have yielded mixed findings regarding the type of search process deployed. Low-level accounts suggest that Kanizsa illusory contours are detected automatically using bottom-up processes because they produce efficient search patterns (Davis & Driver, 1994, 1998). High-level accounts suggest that due to inefficient search patterns, the process is top-down and that cognitive resources are needed to infer the illusory contour due to inefficient search patterns (Grabowecky & Treisman, 1989; Li et al., 2008). Illusory contour stimuli also consist of a grouped surface that usually reveals a brightness enhancement, and these components are involved in guiding search (see Chen et al., 2018; Conci et al., 2006; Conci et al., 2007a, 2007b; Stanley & Rubin, 2003). Contour and surface completions seem to be processed separately (Chen et al., 2018), and visual search with illusory contour stimuli can be guided without contour inference (Conci et al., 2006).

If illusory contour inference is relevant for the search process, contour clarity may play a role in guiding search. This might be the case especially if the inference of the illusory contour, according to high-level accounts, requires resources that slow down the search process. Since past research has shown that line terminations guide search while illusory contours do not (Li et al., 2008), contour clarity should be also relevant in guiding search. To our knowledge, the effect of clarity of illusory contours has not been previously systematically examined in visual search tasks.

The present study

The aim of the current study is to examine whether the clarity of Kanizsa-type illusory contours impacts visual search. This will be examined by (a) manipulating clarity via inducer size, and (b) manipulating clarity via line endings. We will also confirm whether the results of these manipulations are only relevant for illusory contour stimuli, by also examining them with nonillusory perceptually grouped stimuli.

In Experiment 1, we will examine search for a Kanizsa illusory triangle target amongst Kaniza illusory triangle distractors (Li et al., 2008; Zupan & Watson, 2020), and compare this with search for a nonillusory perceptually grouped triangle target amongst nonillusory perceptually grouped triangle distractors. For each type of stimuli (illusory and nonillusory), we will manipulate the size of the inducers for both target and distractor stimuli in three conditions. Both size and inducer separation influence the clarity of illusory contours (Shipley & Kellman, 1992). However, as this is a visual search study, we have opted for manipulating inducer size only, as increasing inducer separation in multielement displays would interfere with the stimulus percept by forming groups by proximity with neighboring inducers from another figure. Hence, inducer separation will be held constant. Manipulating a single factor (size or separation) is sufficient to affect illusory stimulus clarity (see Shipley & Kellman, 1992). Of note is that search will likely be affected by size because small items are less distinguishable in peripheral vision than large items, and more eye movements will need to be made. To overcome this limitation, search for nonillusory contours using the same procedure will confirm whether search is more affected by size manipulations for illusory in comparison to nonillusory stimuli.

Experiment 2 will examine clarity changes determined by line ends (Lesher & Mingolla, 1993). Here, Kanizsa inducers will consist of concentric rings with missing arcs, and the number of arcs will be manipulated to explore clarity. Similarly to Experiment 1, search for nonillusory configurations constructed from the same type of inducers will confirm whether the results of Kanizsa search are due to contour clarity, as here the manipulation will not result in a clarity reduction.

Given that in Experiment 1, the size manipulation will also alter the surface representation of the illusory figure across the three conditions, Experiment 3 will examine whether and to what extent alteration in surface representations might have impacted search patterns. Surface representations have been found to guide search in contexts consisting of nonillusory and illusory stimuli (e.g., Conci et al., 2007a, 2007b). However, the representation of an illusory surface is relatively crude (Conci et al., 2007a), and it has been suggested that in search contexts where all stimuli are illusory, the surface representation may be too crude to guide search in comparison to tasks where stimuli are illusory and nonillusory (Zupan & Watson, 2020). Experiment 3 will examine search for a Kanizsa-like shape formed from "smoothed" inducers, which alter the illusory surface representation (e.g., Chen et al., 2018; Stanley & Rubin, 2003), and compare to search for standard Kanizsa stimuli used in Experiment 1.

We hypothesize that clarity reduction of illusory contours in Experiments 1 and 2 will produce less efficient search, and that illusory stimuli will be more affected by the size and line-end manipulations than search with nonillusory stimuli. The findings of this study will contribute to the literature by showing whether the clarity of the illusory objects due to different luminance levels, camouflage, or occlusion, can affect attentional processes.

Method

The study was approved by the Psychology Research Ethics Committee at the University of Belgrade, Protocol #2021-002.

Experiment 1

In Experiment 1, we will assess visual search for a Kanizsa illusory triangle target among Kanizsa illusory triangle distractors. Thus, the aims of Experiment 1 will be to examine (a) whether search patterns differ depending on the clarity based on inducer size of Kaniza-type illusory figures, and (b) whether these patterns are distinct from search patterns for nonillusory figures.

Participants

We used MorePower 6.0. (Campbell & Thompson, 2012) to calculate the sample size. To detect a medium effect size of $\eta_p^2 = .13$ a power level at 0.8 and a constant at an alpha level of .05, in a 2 (stimuli type) × 3 (inducer size) × 4 (display size) repeated design would require a sample size of 18 participants. This is consistent with the typical sample size numbers required for this type of research (10–25 participants). Participants will receive no compensation for their participation.

Stimuli and apparatus

All stimuli will be made available on OSF (https://osf.io/qkw6f/?view_only=879ebeb2d2984fe89a2d10f84b0cdb1e). Stimuli will be presented on a 15-in. LCD panel at a resolution of 1,980 × 1,080 pixels. The monitor will be positioned at eye level at a viewing distance of approximately 60 cm and the subjects' head movements will be constrained with a chinrest. The DMDX program (Forster & Forster, 2003) will be used to present the stimuli and record the responses. In the first block, the stimuli will consist of Kanizsa-type illusory figures, consisting of black inducers presented against a white background. The target will be a Kaniza illusory triangle oriented upwards. Distractors will be Kanizsa illusory triangles oriented downwards (see Fig. 1a). The stimuli will be presented against a white background. Inducer separation will be fixed to 30 mm (0.28° of arc) in all three conditions. In three conditions, three different inducer sizes will be used with radii of 6, 12, and 18 mm (0.57°, 1.14°, 1.71° of arc). The support ratios of the illusory contour figures (defined by the ratio of the luminance-defined edge length and the entire edge length; Shipley & Kellman, 1992) are as follows: 0.29 for the inducer size of 0.57.°, 0.44 for the inducer size of 1.14° and 0.55 for the inducer size of 1.71°. In the second block, the stimulus configuration will be similar, except that inducers will be oriented outwards and grouped as a nonillusory triangle (see Fig. 1b). The target nonillusory triangle will be oriented upwards, while the distractors will be oriented downwards.

Design and procedure

All participants will read and sign informed consent forms before proceeding with the experiment. They will be informed about the confidentiality of the data and that it will be published in an anonymous format. Participants will then complete a form to provide information about their age, sex, and any visual impairments. In one block, participants will complete search tasks with illusory stimuli, while in the other block, they will complete search tasks with nonillusory stimuli. The order of the blocks will be counterbalanced.

Each block will consist of three conditions with a clarity manipulation. Each clarity condition will contain 160 trials and conditions will contain 4, 6, 8, or 12 items in the search array. The clarity conditions will be counterbalanced across participants. Trials with different display sizes will be presented in random order. There will be additional 16 catch trials where there will be no target and no response will be required (Zupan & Watson, 2020). The purpose of the catch trials will be to ensure the participants are not searching through only half the display. There will be 16 practice trials. A trial will consist of a blank screen for 1,000 ms, followed by a fixation cross for 1,000 ms, after which the search display will be presented until a response is given or until 3,000 ms elapsed (see Fig. 2 for a trial schematic). The task will be to indicate the location of the target, whether it is on the left or right side of the screen (Al-Aidroos et al., 2012; Blagrove & Watson, 2010; Zupan & Watson, 2020). Participants will indicate the location of the target by pressing the left shift key if the target is on the left side of the screen, or the right shift key if the target is on the right side of the screen on a standard computer keyboard. Density will not be controlled, as it is not possible to maintain a constant separation between stimuli for the largest display sizes and the condition with the largest inducer size. However, past research has suggested that search rates of Kanizsa illusory figures when density was controlled (Li et al., 2008) were similar to those when it was not controlled (Zupan & Watson, 2020) hence we do not expect this to influence the findings. For incorrect responses or if responses are not provided within the 3,000 ms exposure time, "incorrect" or "no response" feedback will be given (except for catch trials). For incorrect catch trials, if a response is given instead of being withheld, the feedback "incorrect" will be provided.

Experiment 2

In Experiment 2, we will examine (a) whether visual search patterns with Kanizsa figures will differ depending on the clarity based on the number of line ends when inductors

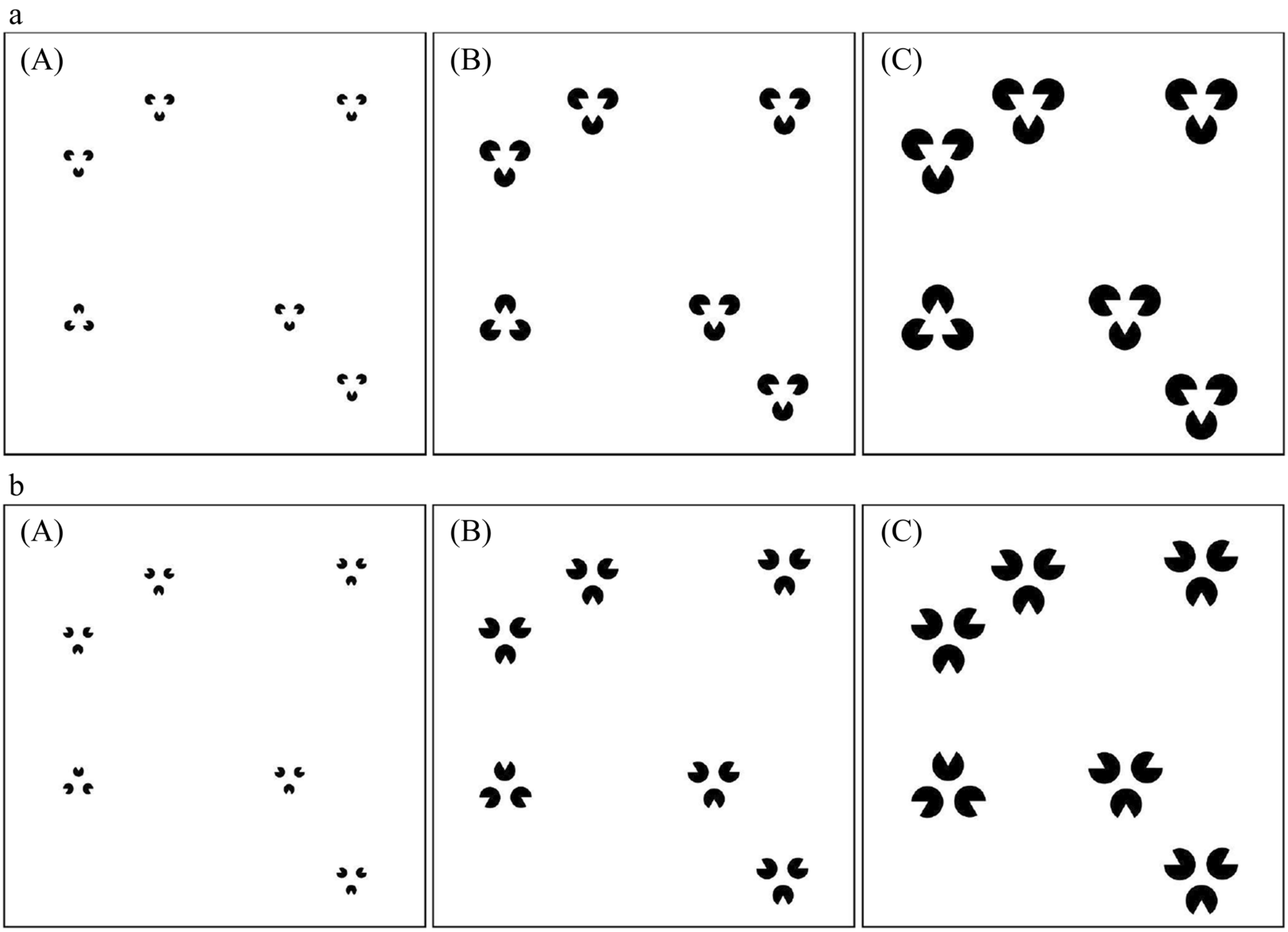

Fig. 1 **a** Illusory stimuli in Experiment 1. Panels represent conditions with different inducer size from top left to bottom right (0.57.°, 1.14°, 1.71°). **b** Nonillusory stimuli in Experiment 1. Panels represent conditions with nonillusory stimuli formed from different inducer sizes from top left to bottom right (0.57.°, 1.14°, 1.71°)

are formed of concentric circles with missing arcs (Lesher & Mingolla, 1993), and (b) determine whether this differs from search for nonillusory concentric ring inducer configurations.

Participants

The sample size will be the same as in Experiment 1. Participants will be newly recruited for Experiment 2.

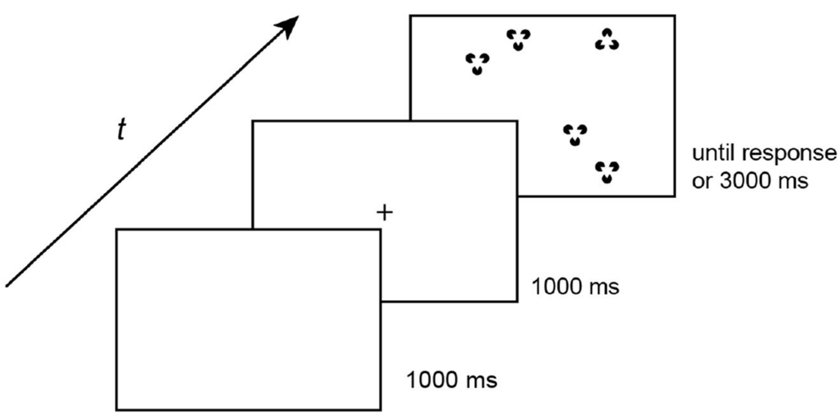

Fig. 2 Schematic of a search trial in Experiment 1

Stimuli, apparatus, design, and procedure

The stimuli, design, apparatus, and procedure will be similar to Experiment 1. The difference in Experiment 2 will be the composition of the inducers—here, inducers will be formed from concentric circles with missing arcs. Similarly to Experiment 1, there will be a block with illusory figure stimuli and a block with nonillusory figures. The order of the blocks will be counterbalanced between participants. In each block, there will be three conditions. Illusory and nonillusory stimuli will be formed of concentric-ring inducers consisting of a varying number of lines: 2, 3, and 5. Line width will be held constant at 2 mm (visual angle 0.01°). An example of stimuli for Experiment 2 is presented in Figure 3a (Kanizsa figures) and 3b (nonillusory figures).

Experiment 3

Experiment 3 will examine the impact of altered surface representation on search performance. This will be done by comparing search performance of Kanizsa-like figures with smoothed inducer edges, to standard Kanizsa figures used in Experiment 1.

Participants

The sample size will be the same as in Experiments 1 and 2.

Stimuli, design, and procedure

There will be two conditions with stimuli types (see Fig. 4). In one condition, stimuli will be the same as in Experiment 1 (i.e., Kanizsa-type figures with inducer radii of 12 mm; 1.14° of arc). The other condition will be similar, except that inducer edges will be smoothed to eliminate sharp edges and collinearity of edges (Stanley & Rubin, 2003). As in the previous experiments, stimuli types will be presented in two blocks, counterbalanced across participants. Displays will be comprised of 4, 6, 8, or 12 items. As in the previous experiments, there will be 160 trials per condition, resulting in 360

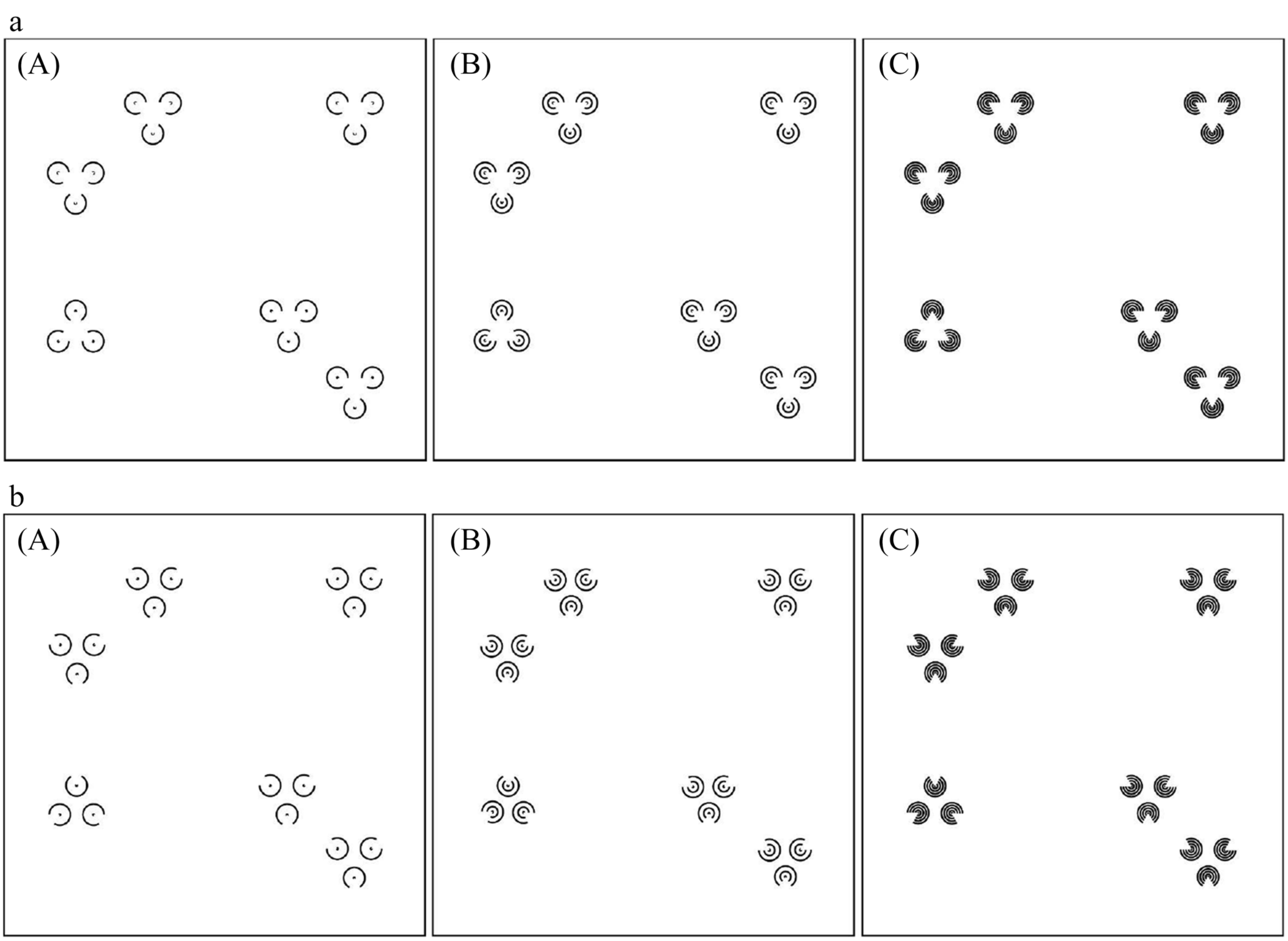

Fig. 3 **a** Stimuli in Experiment 2. Panels represent conditions with illusory stimuli formed from a different number of concentric rings from top left to bottom right (2, 3, 5). **b** Stimuli in Experiment 2. Panels represent conditions with nonillusory stimuli formed from a different number of concentric rings from top left to bottom right (2, 3, 5)

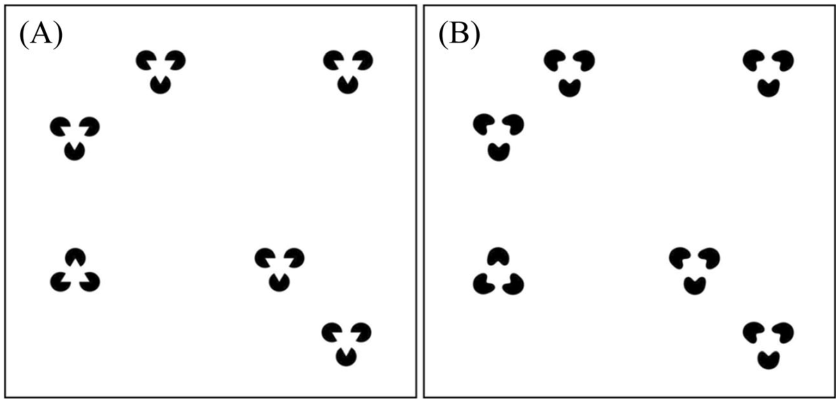

Fig. 4 Stimuli in Experiment 3. The first panel represents conditions with illusory stimuli with edges used in Experiment 1, while the second panel represents illusory configurations with smoothed edges

experimental trials. Additionally, there will be 16 practice trials and 16 catch trials.

Planned analysis

Raw data will be publicly available on OSF (https://osf.io/qkw6f/?view_only=879ebeb2d2984fe89a2d10f84b0cdb1e). All data will be analyzed with JASP (Version 0.16.4; JASP team, 2022). Catch trial accuracy will be analyzed to confirm whether participants have searched over the entire display and if low (<10% per experimental condition) will be removed from further analysis. Reaction times (RTs) < 200 ms will be excluded from the analysis. The main independent variables will be stimuli type, clarity condition and display size, while the dependent variables will be RT and accuracy.

Search slope values, mean correct RTs as a function of display size for each of the three conditions, and mean percentage error rates for each condition will be calculated. For Experiments 1 and 2, respectively, a within-subject comparison will be conducted, 3 (clarity condition: small, medium, large in Experiment 1, and 2,3,5 lines in Experiment 2) × 4 (display size: 4, 6, 8, or 12 items) × 2 (stimuli type: illusory vs. nonillusory). A further 2 (stimuli type: illusory vs nonillusory) × 2 (experiment: 1 and 2) × 4 (display size: 4, 6, 8, or 12 items) mixed ANOVA will be conducted for the middle inducer size of 1.14° in Experiment 1 and inducers consisting of three concentric rings in Experiment 2, to assess whether mid-level clarity produced similar search performance across the two experiments. For Experiment 3, a within-subject 4 (display size: 4, 6, 8, or 12 items) × 2 (stimuli type: illusory vs smoothed) comparison will be conducted. Further ANOVAs may be conducted to break up any significant interactions. Bonferroni-corrected post hoc comparisons will be performed to indicate any differences between the clarity conditions. For any null findings, Bayesian repeated-measures ANOVAs, followed by Bayesian *t* tests, will be conducted.

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