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Is interpolation cognitively encapsulated? Measuring the effects of belief on Kanizsa shape discrimination and illusory contour formation

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ABSTRACT

Contour interpolation is a perceptual process that fills-in missing edges on the basis of how surrounding edges (inducers) are spatiotemporally related. Cognitive encapsulation refers to the degree to which perceptual mechanisms act in isolation from beliefs, expectations, and utilities (Pylyshyn, 1999). Is interpolation encapsulated from belief? We addressed this question by having subjects discriminate briefly-presented, partially-visible fat and thin shapes, the edges of which either induced or did not induce illusory contours (relatable and non-relatable conditions, respectively). Half the trials in each condition incorporated task-irrelevant distractor lines, known to disrupt the filling-in of contours. Half of the observers were told that the visible parts of the shape belonged to a single thing (group strategy); the other half were told that the visible parts were disconnected (ungroup strategy). It was found that distractor lines strongly impaired performance in the relatable condition, but minimally in the non-relatable condition; that strategy did not alter the effects of the distractor lines for either the relatable or non-relatable stimuli; and that cognitively grouping relatable fragments improved performance whereas cognitively grouping non-relatable fragments did not. These results suggest that (1) filling-in effects during illusory contour formation cannot be easily removed via strategy; (2) filling-in effects cannot be easily manufactured from stimuli that fail to elicit interpolation; and (3) actively grouping fragments can readily improve discrimination performance, but only when those fragments form interpolated contours. Taken together, these findings indicate that discriminating filled-in shapes depends on strategy but the filling-in process itself may be encapsulated from belief.

1. Introduction

Cognitive encapsulation refers to the degree to which a perceptual process operates independently of beliefs, expectations, and other "higher-level" cognitive states[1] (Fodor, 1983; Pylyshyn, 1999). Contour interpolation is a perceptual process that fills-in missing contours on the basis of how surrounding (visible) edges are spatiotemporally related. Is contour interpolation cognitively encapsulated?

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[1] Some use "cognitive" to refer to any mental state, while others use it to refer to those that are post-perceptual. We use the term in the latter sense. That is, cognitive states are typically: instantiated outside of the primary sensory cortices, subject to voluntary control, and manifested as beliefs, expectations, desires, and utilities. This definition is (perhaps necessarily) imprecise, but should be sufficient for interpreting the present data.

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We focus specifically on interpolation because it is *prima facie* a likely candidate for encapsulation. It is phylogenetically primitive (Nieder, 2002), ontogenetically precocious (Kellman & Spelke, 1983; Valenza, Leo, Gava, & Simion, 2006), and (at least in part) physiologically early (Peterhans, von der Heydt, & Baumgartner, 1984; Seghier & Vuilleumier, 2006; Sugita, 1999), all of which imply a limited role for cognitive input. Moreover, while other studies have examined whether attention can alter interpolation (Marcus & van Essen, 2002), or whether interpolation can occur despite the wishes of the observer (Davis & Driver, 2003; Keane, Mettler, Tsoi, & Kellman, 2011), none have examined whether *beliefs or expectations* can extinguish interpolation when it normally occurs or induce interpolation when it normally does not. Addressing this question will be valuable, first, because it will bear on a long-standing debate as to whether the mechanisms of perception operate independently of cognition (Fodor, 1983; Pylyshyn, 1999); and second, because it can inform current models of object perception, in terms of what types of inputs can feed into the process (e.g., Grossberg & Mingolla, 1985; Grossberg & Raizada, 2000; Kalar, Garrigan, Wickens, Hilger, & Kellman, 2010; Seghier & Vuilleumier, 2006).

1.1. Evidence regarding cognitive encapsulation

Studies thus far have yielded only indirect evidence regarding the encapsulation of interpolation. In visual search and multiple object tracking experiments, the attempt to ignore interpolated contours failed to block interpolation effects (Davis, 2003; He & Nakayama, 1992; Keane et al., 2011). In a contour linking study, pictures of complete shapes before a trial did not improve subjects' ability to integrate fragments into a single moving shape (Lorenceau & Alais, 2001). In attentional cuing experiments, the attentional guidance offered by occluded contours could not be removed via pictorial cues that biased observers to interpret edges as disconnected (Pratt & Sekuler, 2001). By contrast, in a subsequent cuing study (Lee & Vecera, 2005), a visual short-term memory task destroyed the attentional guidance afforded by interpolated (but not real) contours. This latter effect does not by itself imply reduced interpolation, however.[2]

Subjective reports also provide clues. Interpolation can create shapes that would be contextually unexpected or semantically nonsensical, suggesting a limited role of cognition (see Fig. 1; Kanizsa, 1985; Kellman, Garrigan, Shipley, & Keane, 2007). At the same time, observers can vacillate between modal and amodal representations or invoke object knowledge to represent the approximate shape edges (Gellatly, 1982; Kellman et al., 2007; see also, Lesher, 1995, esp. pp. 295–296).[3] These subjective reports—although intriguing and worthy of further study—should be regarded with caution, since they may result from the construction or manipulation of representations at relatively late (post-interpolation) stages in visual processing (Kellman, Garrigan, & Shipley, 2005).

Paradigms most relevant to the current study are those that examine the *filling-in*, and not just grouping, of interpolated contours, where 'filling-in' refers to the tendency to represent and rely upon the regions corresponding to the missing contours.[4] In one such study, "fat" and "thin" Kanizsa squares were harder to differentiate when distractor lines appeared near the illusory boundaries (Ringach & Shapley, 1996). This occurred even though subjects knew that the lines were task-irrelevant and even though the lines were well-separated from the inducing edges of the squares. No such impairment was found in a control condition that lacked filled-in contours. In a separate study, when subjects were explicitly and repeatedly told to ignore distractor lines, the discrimination of illusory (but not fragmented) shapes strongly depended on those lines (Keane, Lu, Papathomas, Silverstein, & Kellman, submitted for publication). Others have found a reliance on filling-in regions with standard Kanizsa shapes, noise-corrupted Kanizsa shapes, and spatiotemporal illusory shapes (Gold, Murray, Bennett, & Sekuler, 2000; Gold & Shubel, 2006; Keane et al., 2007; Sekuler & Murray, 2001; Zhou, Tjan, Zhou, & Liu, 2008). A few studies demonstrated attentional modulation of contour filling-in but in all of these cases the integrated elements did not strongly group either because of narrowband spatial frequency composition (Freeman, Sagi, & Driver, 2001), misaligned edges (McMains & Kastner, 2011) or inadequate junction structure (Li, Piëch, & Gilbert, 2008; Rubin, 2001).

The foregoing studies, while not monolithic in agreement, converge on several conclusions: interpolation can proceed even when observers attempt to stop it; attention can modulate interpolation, at least for weakly-grouped elements; and processes subsequent to (or otherwise separate from) interpolation may be relevant for interpreting first-hand reports and psychophysical data, especially when the stimuli are observed for extended durations. What is still unknown, and what we now address, is whether the *strength or existence* of filling-in can be modulated via cognitive expectation.

1.2. Methodology, hypotheses, and rationale

A description of our approach must be prefaced by several clarifications. First, encapsulation is not the same as

[2] The color memory task may have served not to weaken interpolation, but to strengthen the representation of the fragmented array in which the color patches appeared. This memorized configuration essentially may have "out competed" the amodal contours in guiding attention. Such an explanation is rendered more plausible by the facts that observers could not respond until 600 ms after inducer onset, and that interpolation strength may rapidly rise and fall within 200 ms of inducer onset (Keane, Lu, & Kellman, 2007; Lee & Nguyen, 2001). Others have also argued that recently stored stimulus representations can trump the attentional guidance afforded by (currently visible) real and interpolated contours (Zemel, Behrmann, Mozer, & Bavelier, 2002).

[3] Kanizsa (1985) termed post-perceptual representations of non-visible objects "mental integration", and, more recently, Kellman and colleagues (2007) called it "representing on partial information (RPI)". Both authors were referring to processes that were at least partly cognitive in nature.

[4] Grouping and filling-in are not the same. Grouping involves specifying whether disparate elements belong together; filling-in also involves delineating the specific shape that those elements form and using information that appears near the delineated edge. As an example, four similarly oriented "pac-men" may be grouped but they will not cause the visual system to represent and use regions that are between the pac-men (Ringach & Shapley, 1996).