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Created unequal: Temporal dynamics of modal and amodal boundary interpolation

Branka Spehar *, Victor A. Halim

School of Psychology, UNSW Australia, Sydney, NSW 2052, Australia

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ABSTRACT

In this study we manipulate the distribution of contrast polarity reversals in inducing configurations to create novel variants of modal and amodal completion. The novel variants, better equated in their geometric and photometric characteristics offer a superior way to probe similarities and differences in the temporal dynamics that underlie different forms of perceptual completion. We use dot localisation to directly compare the spatial characteristics of modally and amodally interpolated contours at presentation durations ranging from 120 to 300 ms and find robust differences in the spatiotemporal formation of modally and amodally completed boundaries. Modally completed contours are localised more accurately and with better spatial precision across all presentation durations. Our results challenge the assumption that the boundary interpolation system depends solely on the geometrical relatability of inducing fragments and suggest that boundary interpolation depends on the spatial distribution of local luminance relationships. As an alternative to the strong version of the identity hypothesis, we propose that modal and amodal completion are mediated by different mechanisms, triggered by particular configurations of contrast polarity.

1. Introduction

In natural scenes objects routinely occlude each other, have reduced visibility due to noise or variations in illumination, or can be camouflaged against the background. The visual system compensates for the lack of visible information through processes of visual interpolation, able to deliver representations of complete boundaries and continuous surfaces even in the absence of physical discontinuities in the image. These processes are fundamental to visual scene analysis and their precise characterisations remain a challenge.

The two most extensively studied mechanisms capable of overcoming the fragmented visual inputs are often referred to as modal and amodal completion (Kanizsa, 1976, 1979; Kellman, 2003; Michotte, Thines, & Crabbe, 1964). Modal completion phenomena occur when a foreground object is camouflaged against its background, while amodal completion phenomena refer to the process by which completed objects are perceived despite partial occlusion by other objects. In addition to the differences in relative depth of interpolated contours, modally completed contours are accompanied by the robust sensory presence (also known as illusory contours) whereas amodally completed, or occluded contours lack such a vivid sensory experience (Michotte et al., 1964) as illustrated in Fig. 1a and b.

The views regarding the role these phenomenological differences play in the two types of completion differ (Anderson, Singh, & Fleming, 2002; Kellman, Garrigan, & Shipley, 2005; Kellman & Shipley, 1991; Kellman, Yin, & Shipley, 1998). Several prominent models of modal and amodal completion view these phenomenological differences as spurious and reflective of considerations that are not part of the boundary completion process. These approaches share the assumption, 'the identity hypothesis', that the perception of illusory and occluded contours occurs via the same boundary interpolation processes and that the perceived depth ordering of completed boundaries is independent from the processes initiating the boundary completion (Grossberg & Mingolla, 1985; Kalar, Garrigan, Wickens, Hilger, & Kellman, 2010; Kellman, 2003; Kellman & Shipley, 1991; Shapley, Caelli, Grossberg, Morgan, & Rentschler, 1990). According to the identity hypothesis, the visual system uses relationships among visible contour segments to connect oriented edges across gaps and produces interpolated perceptual units that correspond more closely to the actual objects in a scene. The complementary surface interpolation process links visible areas that are similar in surface properties such as colour, texture, but provides little boundary or shape

* Corresponding author.
E-mail address: b.spehar@unsw.edu.au (B. Spehar).

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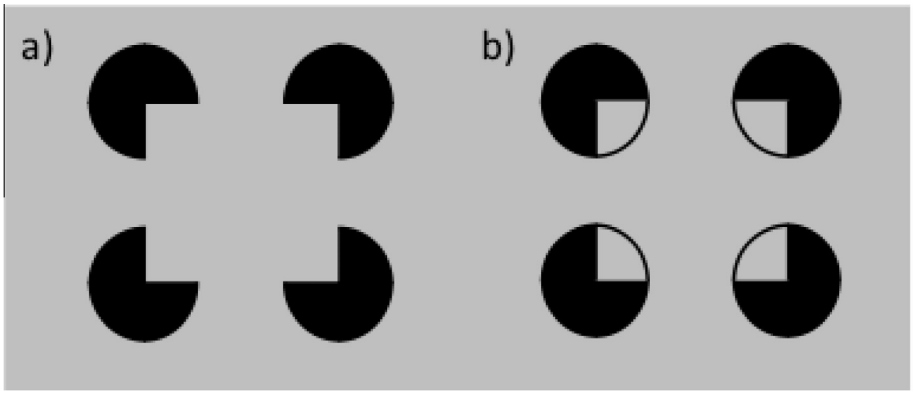

Fig. 1. Traditional configurations for studying (a) modal and (b) amodal completion phenomena.

information by itself, and is confined in its operations by either real contours present in the image or contours interpolated by the boundary interpolation process. The evidence supporting the identity hypothesis has indicated that the interpolated illusory and occluded contours have similar, if not identical, effects on judgments of object unity, perceived shape properties and in many instances affect performance in the same way as the real luminance contours (Gold, Murray, Bennett, & Sekuler, 2000; Kellman & Shipley, 1991; Ringach & Shapley, 1996).

However, in direct contradiction of the identity hypothesis, others have argued that relative depth imposes asymmetric constraints on how of modal and amodal completion processes are generated and have showed that the shape of interpolated contours can change profoundly when a figure undergoes a transition from modal to amodal appearance (Anderson et al., 2002; Singh, 2004). This debate remains open and deeply polarised with the space constraint precluding us from the complete and detailed exposition of numerous qualitative demonstrations and logical arguments used to support either of the theoretical views (Anderson, 2007a, 2007b; Kellman, Garrigan, Shipley, & Keane, 2007a, 2007b).

Instead, we focus our analysis on the spatiotemporal dynamics of the two completion phenomena as numerous studies have indicated that both modal and amodal completion take measurable time. Rather than just comparing the final products of interpolation processes that under some circumstances might become indistinguishable after the completion has taken its course, mapping their *microgenesis*, can potentially reveal the fundamental differences in the formation of modal and amodal contours (Kimchi, Hadad, Behrmann, & Palmer, 2005). Naturally, the duration necessary to achieve any type of visual completion is not fixed but varies depending on the particular spatial, temporal, and task context and for that reason it is imperative to compare the time course of modal and amodal completion under identical circumstances. However due to the explicit or implicit acceptance of the identity hypothesis, most investigations have so far tended to address microgenesis of either illusory (Gold & Shubel, 2006; Guttman & Kellman, 2004; Parks, 1995; Petry & Gannon, 1987; Reynolds, 1981; Spehar & Clifford, 2003) or occluded contour interpolation (Bruno, Bertamini, & Domini, 1997; Guttman, Sekuler, & Kellman, 2003; Rauschenberger & Yantis, 2001; Sekuler & Palmer, 1992; Shore & Enns, 1997), but not both, often under the assumption that to address one is to address the other.

Consequently, direct comparisons of the temporal dynamics of modal completion under similar circumstances are quite rare, although they offer potentially the most relevant empirical evidence concerning the identity hypothesis. Paradoxically, even when such empirical evidence exists, it seems to remain largely unnoticed. For example, Ringach and Shapley's (1996) study, famous for showing that both modally and amodally completed shapes are discriminated with comparable levels of precision and accuracy, also reported that the comparable level of shape discrimination performance breaks down at short stimulus durations. This rarely discussed, though as important, feature of this study was revealed by using a backward masking paradigm (Ringach & Shapley, 1996; Exp. 6). The illusory contour inducers were presented at variable time durations (80–200 ms) immediately followed by local masks. It was shown that thin-fat shape discrimination thresholds decreased as a function of exposure duration with an asymptote performance being reached at approximately 117 ms. When a similar procedure was repeated with amodal completion configurations at two pre-mask exposure durations of 117 and 167 ms, the performance with amodally completed shapes was significantly worse at a shorter duration of 117 ms compared to modally competed shapes. At a longer duration of 167 ms the performance was similar for both types of completion, suggesting that the exposure time necessary to reach the same asymptote in shape discrimination accuracy requires additional 50 ms for amodal compared to modal completion.

In another study, Gegenfurtner, Brown, and Rieger (1997) measured presentation time required for accurate localisation and identification of modally and amodally completed Kanizsa triangle embedded in an array of distractors made up of the same inducing elements but in random orientations. Localisation task required observers to report whether the target figure appeared on the left or right side relative to the central fixation point while in the identification task they had to report whether the triangular target shape was pointing upward or downward. The presentation times varied from 13.8 to 1000 ms and it was found that modally completed shapes had an average localisation threshold of 136 ms compared to amodally completed shapes with an average threshold of 285 ms. The average identification thresholds took approximately 20 ms longer for both modally and amodally completed targets.

These findings bring into question claims regarding the identity of modal and amodal completion which are based at durations/processing times longer than 100–200 ms. For example, in a strong support for the identity hypothesis, Gold et al. (2000) used the image classification technique to show the identical spatial layout of interpolated contours used in a shape discrimination task with both illusory and occluded Kanizsa configurations. However, the exposure duration of 500 ms precludes any attempts to compare the similarity of classification images at shorter durations. Similarly, Guttman and Kellman (2004) used dot localisation task to measure microgenesis of illusory contours and found that the precision and accuracy reached an asymptote at 120 ms, consistent