Distinctly perceptual possibilities:
Amodal completion is disrupted by visual, but not cognitive, load

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Abstract: Across developmental, cognitive, and social psychology, there has been a growing interest in studying when and how people represent mere possibilities---states of the world that have not been realized. Recent research has extended this growing interest to visual paradigms and has argued that people may literally perceive such mere possibilities, e.g., seeing the shape that would be made if two smaller shapes were put together (Guan & Firestone, 2020). An important open question is whether the representation of possibilities observed in these visual paradigms should be understood as a part of a more general system underwriting possibility representations or whether it is best understood as a separate and distinctly perceptual phenomenon. Across three studies, we provide clear evidence for the latter hypothesis. Employing the most widely-studied visual paradigm that involves the perception of possibilities, amodal completion, we demonstrate that the representation of possibilities in this visual task is selectively disrupted by perceptual load but not working-memory load. This provides clear evidence that the key processes underlying the perception of possibilities occur before the information reaches high-level cognition. The representation of such possibilities is distinctly perceptual.

Public significance statement: This study demonstrates that the processes supporting the perception of possibilities operate prior to and separately from the cognitive capacity to think and reason about what is possible.

Keywords: possibility, perception, attention, load theory, high-level cognition

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Introduction

One remarkable capacity of the human mind is the ability to represent possibilities---states of the world that have not been, and may never be, realized. Such representations can be found throughout cognition, whether one is considering potential meals to make for dinner, inferring the possible shapes of a car that's partially occluded, or daydreaming about what would have happened if you had become an artist instead of an academic (Phillips & Kratzer, 2024). Most of the research on this capacity has focused on higher-order cognition: how we represent and reason about the different possibilities and the role that such representations play in domains such as language (Kratzer, 2012; Stalnaker, 2014), causal reasoning (Lewis,1973; Pearl, 2009; Gerstenberg, Goodman, Lagnado, & Tenenbaum, 2021), judgment (Woolfolk, Doris, Darley, 2006), or decision making (Morris, Phillips, Huang, Cushman, 2021).

Intriguingly, evidence suggests that similar representations may also exist in the perceptual domain. For example, recent studies argued that people perceive merely possible objects automatically---objects that would emerge if two smaller parts were put together (Guan & Firestone, 2020; Guan, Schwitzgebel, Hafri, & Firestone, 2020). One critical but unanswered question is whether such perceptual possibilities should be understood as part of the same capacity found throughout high-level cognition, or whether they uniquely reflect the visual system's ability to infer possible states, and should thus be seen as a separate, distinctly perceptual phenomenon.

Thus, we examine whether the generation of visual possibilities relies on higher-level cognitive processes, such as working memory and cognitive control, or whether it depends primarily on lower-level perceptual processes. We capitalize on a robust phenomenon that involves perceptual inferences of possible objects: amodal completion (Michotte et al., 1991; Rauschenberger & Yantis, 2001; Sekular & Palmer, 1992). We hypothesized that if amodal completion relates to a more general capacity of representing possibilities, which prior work has shown is sensitive to cognitive load manipulations (Phillips & Cushman, 2017), taxing higher-order cognition should disrupt amodal completion. Conversely, if it reflects a primarily visual phenomenon, amodal completion should be selectively attenuated during high perceptual, but not cognitive, load.

Methods and procedures

Participants. We planned a priori to run 60 participants in Experiment 1, 120 in Experiment 2, and another 120 in Experiment 3; participants were recruited via Amazon Mechanical Turk (www.mturk.com), using Cloud Research (www.cloudresearch.com), which facilitated screening participants to those in the United States with a high approval rate (>95%). Data from participants were excluded from the final analysis following the same criteria for all studies (for details, see Data Analysis). This left data from 51 participants for Experiment 1 (M_{age} = 39.8, SD_{age} = 11.6, 23 female); 82 participants for Experiment 2 (M_{age} = 40.3, SD_{age} = 10.3, 33 female); and 80 participants for Experiment 3 (Mage = 41.94, SDage =12.13, 40 female). These final numbers of participants are well above the sample sizes of similarly designed previous studies (n=19-31; e.g., Lier, Leeuwenberg, & van der Helm, 1995; de Wit & Van Lier, 2002).

Stimuli. The stimuli and task design were based on previous studies investigating amodal completion (van Lier, Leeuwenberg, & van der Helm, 1995; de Wit & Van Lier, 2002). Three different red shapes served as prime stimuli. These shapes were either drawn in front of a blue rectangle and were thus fully visible, or they were partially occluded by the rectangle, thus leaving ambiguity in what the full shape could be; this latter condition served as the amodal completion condition. When visible, the red shapes were either “likely” or “unlikely” completions of the occluded shape (see Figure 1A). Test stimuli consisted of two red target shapes and the blue rectangle, always moved to new locations so that the red shapes were never occluded. On half of the trials, the test shapes matched in identity; on the remaining half of trials they did not match. Each stimulus subtended ~4 to 6 degrees of visual angle (DVA). As these studies were run online on participants’ personal computers (using www.testable.org), stimulus sizes were adjusted across monitors using the calibration feature implemented in Testable.

Procedure. On a given trial, participants were shown a fixation cross for 500ms, followed by the prime stimulus for 750ms, and after a brief gap (~17ms), the test stimulus which remained on the screen until response (Figure 1B). Participants were instructed to indicate whether the final pair of red shapes was identical or not by pressing one of two keys (‘j’ for match or ‘f’ for no-match) as quickly as possible. The test shapes were always from the same shape category as the prime. On half the trials, these shapes were identical and on the remaining half of the trials the two shapes were different from one another. Critically, the prime stimulus was not predictive of whether the shapes were the same or not. This was also emphasized in the instructions and participants were told to focus on the critical comparison between the final red stimulus pair and that the prior stimulus was not relevant to this task.

Procedure specific to Exp. 1. There were 8 experimental blocks of 36 trials each. The three prime shapes and types (amodal, likely, unlikely) were counterbalanced within each experimental block, and the order of trials was fully randomized.

Procedure specific to Exp. 2. An additional working memory task with two load conditions was added, where participants were asked to remember 1 (low load) or 6 (high load) digits (Lavie et al., 2004; Fockhert & Bremner, 2011). The to-be-remembered digits were presented centrally for 1,500ms prior to the onset of a trial and had to be remembered for three consecutive trials, before participants were prompted with a number and had to indicate whether that number was part of the remembered sequence or not (Figure 1C). Trials were separated into two blocks of 27 priming trials with 9 working memory trials each. Working memory load was blocked, and blocks were counterbalanced across participants. All other trial types were randomized.

Procedure specific to Exp. 3. Experiment 3 manipulated perceptual load using a visual search task. The prime stimulus was surrounded by an array of four letters, of which one was the target letter "X" and the others were nontargets (Lavie, 2006). In the high-load condition, the nontarget letters were "Y", "K", or "V"; in the low-load condition, all non-target letters were "O", making the target easy to find (Lavie, 2006; Cartwright-Finch & Lavie; 2007). Participants were instructed to attend to the prime in the center of the screen and also locate the target letter "X" in the search array. After responding to the target shapes in the matching task, participants were asked to indicate the location of the visual search target "X". The search letters were always located at 0, 90, 180, and 270 degrees around the prime, and the response screen included the same locations that were now labeled 1-4, and participants pressed the key associated with the location of the search target letter (Figure 1D). They were also given the option to press the "0" key if they did not find the target. Participants completed one block of 216 trials, with full randomization and counterbalancing of high and low load trials.

Familiarization and practice trials. Across all studies**,** prior to the main task, participants were familiarized with the stimuli by freely viewing the stimuli and then completing a series of practice trials for each of the experimental parts.

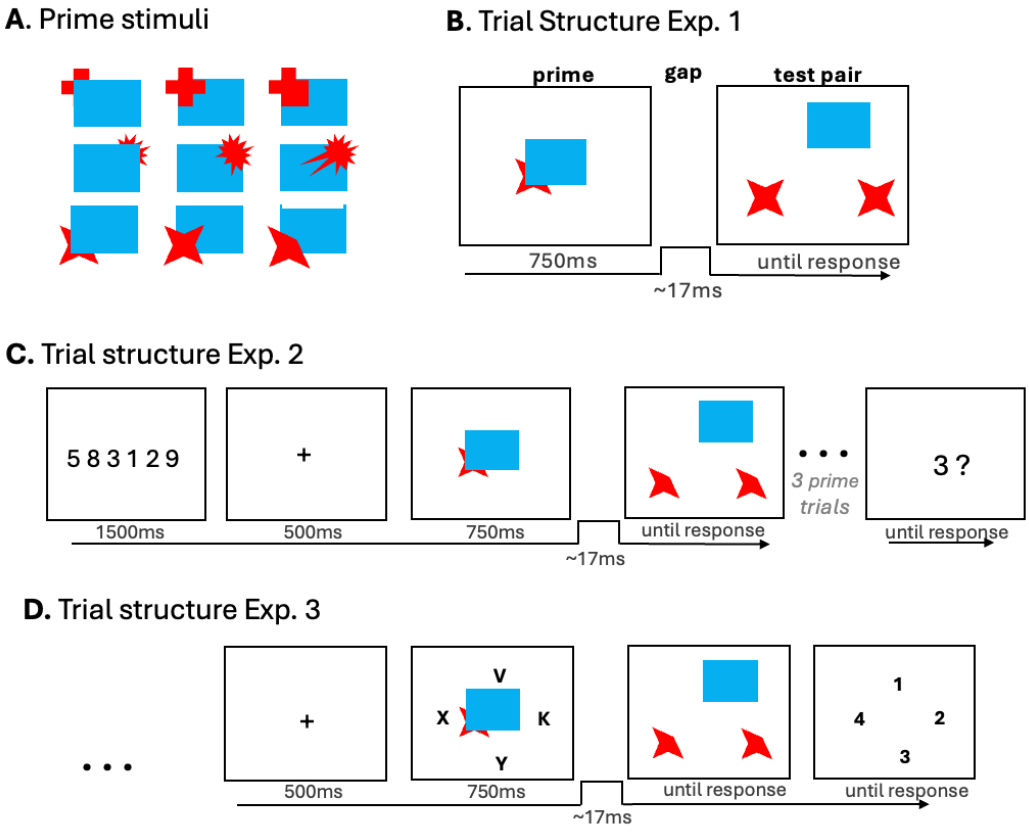

Figure 1. Stimuli and trial structures. A) For the prime stimuli, three different red shapes were used (from top to bottom) that were presented simultaneously with a blue rectangle that would either occlude part of the shape (left column), or not. If not occluded, red shapes were fully visible, either in 'likely' configurations (middle column), or 'unlikely' configurations (right column). B) In Experiment 1, each trial started with a fixation (500ms - not shown), after which one of the prime stimuli was presented for 750ms. After a brief gap, where only a white screen was shown, the test stimuli were presented: these consisted of two shapes from the same category as the prime and could either be exactly the same shape ('match') or not ('non-match'). The example depicts an amodal completion prime with a matching test pair. C) In Experiment 2, a working memory task was added. Participants remembered either 6 digits (as shown here - high load) or 1 digit (low-load), and were tested on their working memory after three priming trials. D) In Experiment 3, a visual search display was presented simultaneously with the prime stimulus and participants had to find the location of the X. After completing the identity matching task, they indicated the location of the target letter X by pressing one of four buttons corresponding to the search locations (1-4). The visual search either contained 3 difficult distractor letters (as shown here – high load), or the same distractor letter 'O' (low-load).

Analysis.

Data Cleaning:

Across experiments, all data were excluded from participants who had an average accuracy score below 90% on the primary identity matching task. Individual trials were excluded if the response time was faster than 300 *ms*. Because of the long-tailed distribution in response times, we also excluded the slowest 2.5% of response times in each experiment. Additionally, all data

were excluded from participants who had more than 10% of their data removed during trial-level exclusions.

For Experiments 2 and 3, which had additional accuracy scores for the cognitive and perceptual load tasks, we excluded all data from participants who scored lower than 85% on these tests in the "low" load condition. This ensured the data were from participants who were actively engaged in the additional load tasks.

Model comparison:
All data were analyzed in R using linear mixed-effects models (Bates, Mächler, Bolker, & Walker, 2015), fit with a maximal random-effects structure (Barr, Levy, Scheepers, & Tily, 2013). Statistical significance was determined via model comparison of minimally differing models (Bates, et al., 2015). The decomposition of interaction effects and pairwise comparisons were analyzed using estimated marginal means (Lenth, 2025).

Main analysis:
The main dependent variable of interest was response times on correct trials to matching test pairs, based on previous work showing that the key priming effects only occur for identical test pairs (Beller, 1971; Sekuler and Palmer, 1992; de Wit and van Lier, 2002). Response time data was log-transformed for normality, and mean response times were separated into the three critical conditions of 1) the prime being *congruent* with test shape; 2) the prime being *incongruent* with test shape; 3) or the *amodal* prime that is ambiguous in terms of its completion shape. For Experiments 2 and 3, load was added as a second factor into the analyses.

All data, analysis code, and study materials are publicly available at: https://doi.org/10.7910/DVN/XST12H.

Results

Experiment 1: Assessing visual possibilities with amodal completion task

Experiment 1 used an amodal priming task to assess participants' representation of visual possibilities (Fig. 1B). We hypothesized that participants would be faster in responding to the identity-matching task if the task-irrelevant prime matched the shapes relative to when it did not, and that amodal primes would result in intermediate response times.

We found a significant effect of prime type (congruent vs. amodal vs. incongruent), $X^2(2) = 68.51$, $p < 0.0001$ (Figure 2) . Pairwise comparisons using estimated marginal means revealed that participants were faster on congruent prime trials ($EMM_{logRT} = 6.38$, $SE_{logRT} = 0.024$) relative to amodal prime trials ($EMM_{logRT} = 6.42$, $SE_{logRT} = 0.024$), t.ratio = -5.88, $p < .0001$, and critically, also faster on amodal prime trials than on incongruent prime trials ($M_{logRT} = 6.47$, $SD_{logRT} = 0.025$), t.ratio = -7.76, $p < .0001$. These results indicate that participants automatically represent possible completions of the occluded shape, validating this paradigm for assessing visual possibilities.

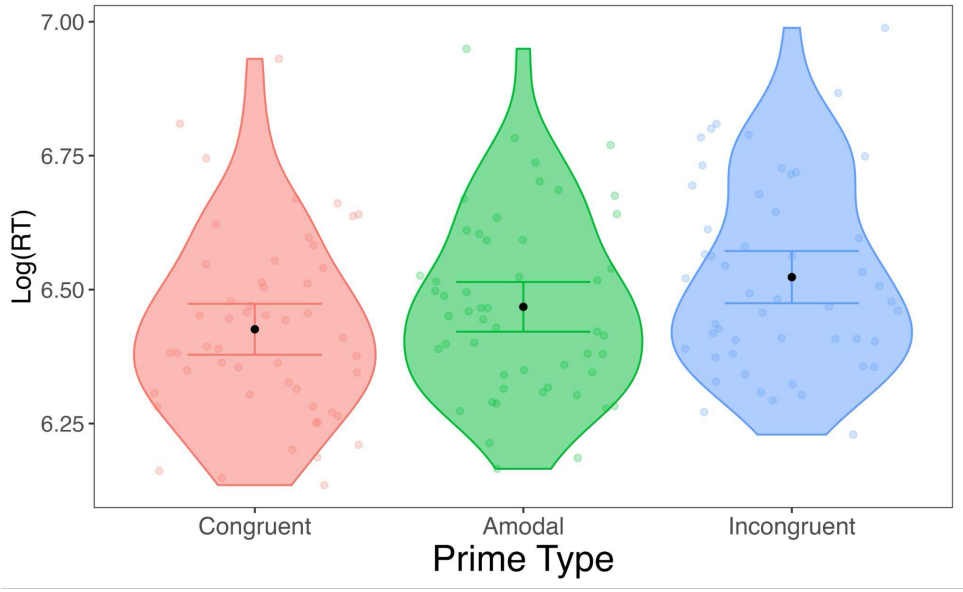

Figure 2. Log-transformed response times for correctly answered match trials as a function of Prime Type. Colored points depict individual participants' means per condition; dark central points depict the condition mean, and error bars represent +/-1 SEM. Statistical results showed that all three conditions differed reliably from one another.

Experiment 2 and 3: Effects of cognitive and perceptual load on amodal priming

The next set of experiments tested the roles of perceptual and cognitive processes in generating and maintaining visual possibilities by employing a dual-task structure. Experiment 2 added a secondary working memory task to tax higher-level cognition, and Experiment 3 used a visual search task to engage earlier perceptual-attentional processes (see Figure 1C+D for task structure; for similar manipulations, see Lavie, Hirst, DeFockert, & Viding, 2004).

Experiment 2: Comparisons of linear-mixed effects models revealed a main effect of prime type (congruent vs. amodal vs. incongruent): $X^2(2) = 69.26, p < 0.001$. Furthermore, high working memory load slowed response times in the priming task compared to low load $X^2(2) = 140.26, p < 0.001$, showing that the high vs. low load manipulation had a strong effect on response times overall. The critical question was whether this cognitive load manipulation would affect the representation of visual possibilities, as would be indicated by a prime × load interaction effect. However, we did not find evidence for an interaction, $X^2(2) = 0.18, p = 0.914$ (Figure 3a). This

lack of interaction arose because, at both the low and high load conditions, we find a pattern that mirrors that of Experiment 1. For both, the Congruent primes elicited faster response times than than Amodal primes (low load: *t*.ratio = -3.71, p = .001; high load: *t*.ratio = -3.27, p = .004), and Amodal primes elicited faster response times than the Incongruent primes (low load: *t*.ratio = -3.22, p = .005; high load: *t*.ratio = -2.21, p = .076).

In sum, we found that while our load manipulation had a strong impact on response times overall, it did not affect the visual representation of possibilities in our amodal completion priming task. This suggests that higher-level cognitive resources like working memory are not necessary for the generation or maintenance of perceptual possibilities.

Experiment 3: Comparisons of linear-mixed effects models again revealed a main effect of prime type (congruent vs. amodal vs. incongruent), $X^2(2) = 38.98, p < 0.001$. Furthermore, high perceptual load slowed response times in the priming task compared to low load, $X^2(2) = 51.33, p < 0.001$, showing that the perceptual load manipulation had a strong effect on response times overall. Critically, however, here we also found evidence of a strong interaction effect, $X^2(2) =$ 18.30, $p < 0.001$ (Figure 3b). Subsequent tests showed that in the *low load* condition, the pattern matched that observed in Experiments 1 and 2: Congruent primes elicited faster response times than Amodal primes (*z*.ratio = -5.09, p < .001) and Amodal primes elicited faster response times than the Incongruent primes (*z*.ratio = -2.11, p = .088). By contrast, in the *high load* condition, this pattern shifted. While the Congruent primes elicited slightly faster response times than Amodal primes (*z*.ratio = -2.03, p = .011), the Amodal primes did not elicit faster response times than the incongruent primes (*z*.ratio = -0.80, p = .703).

This pattern of results indicates that perceptual load disrupted the visual representation of possibilities in our amodal completion priming task, supporting the idea that generating and representing visual possibilities relies on low-level perceptual processes within the visual system itself.

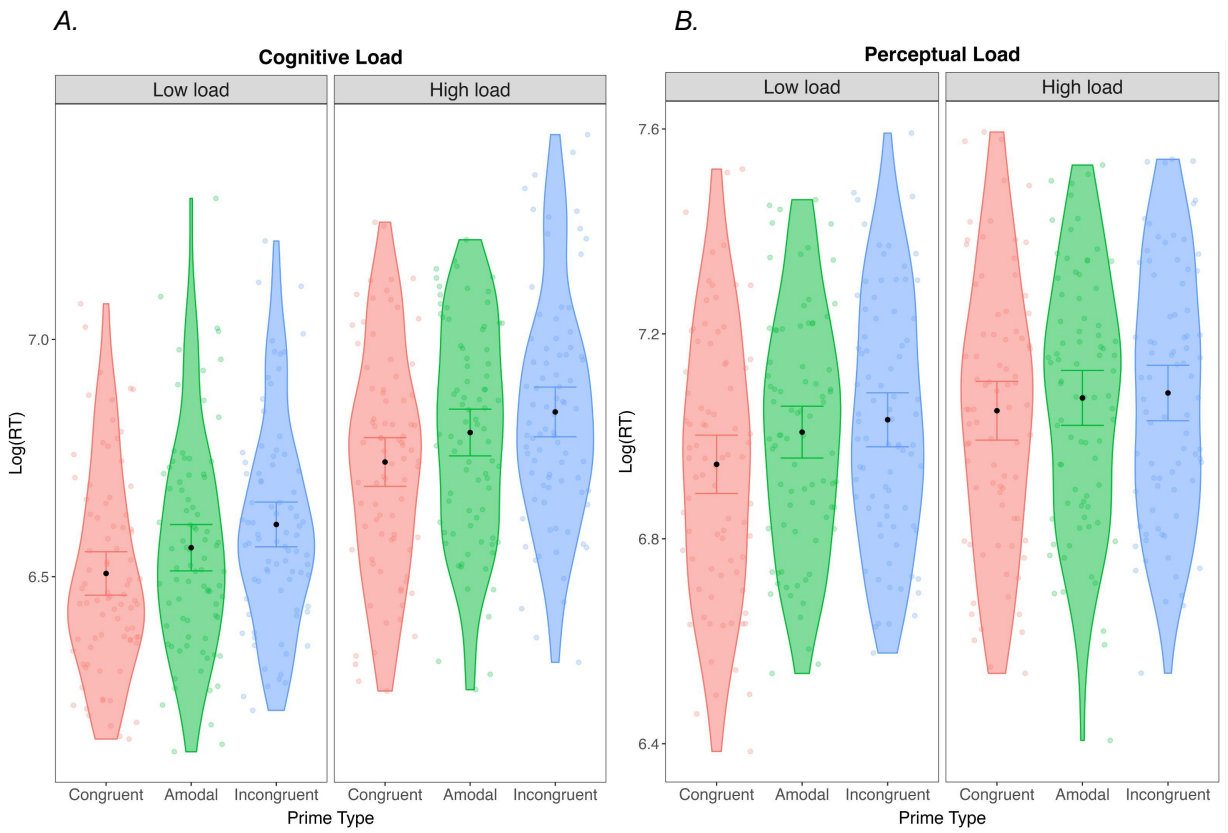

Figure 3. Log-transformed response times for correctly answered match trials as a function of Prime Type for both Cognitive Load, Experiment 2 (**A**), and Perceptual Load, Experiment 3 (**B**). Low load conditions are presented in the left facets, and high load conditions are presented in the right facets. Colored points depict individual participant means per condition; dark central points depict the condition mean, and error bars represent +/-1 SEM. Both high cognitive and perceptual load resulted in slower RTs overall, but only the perceptual load manipulation resulted in an interaction with Prime Type.

Discussion.

Building on the growing interest in the representation of possibilities in high-level cognition (Johnson-Laird & Ragni, 2020; Leahy & Carey, 2020; Phillips & Knobe, 2018), recent research has argued that people may literally perceive such mere possibilities (Guan & Firestone, 2020, Guan, Schwitzgebel, Hafri, & Firestone, 2020). Across a series of three studies, we tested whether the representation of possibilities observed in these visual paradigms should be understood as a part of a more domain-general system underwriting possibility representations, or whether it is best understood as a separate and distinctly perceptual phenomenon.

Using an amodal completion priming paradigm that enables the direct and objective measurement of perceiving perceptual inferences, we demonstrate that the visual system can

represent multiple perceptual possibilities (Experiment 1), and that the representation of these possibilities is not affected by cognitive load (Experiment 2) but is affected by perceptual load (Experiment 3). The perceptual vs cognitive load manipulations used in the present study are based on the well-established load theory of attention that postulates that there are two separate mechanisms that determine how information is processed, and that each depends on different kinds of load: perceptual, that is the additional sensory engagement during stimulus encoding, and cognitive – the employment of capacity-limited control and working memory systems (Lavie, 1995; Lavie, 2006; Lavie, Hirst, DeFockert, & Viding, 2004). Our results provide clear evidence that the key processes underwriting the perception of possibilities are affected by perceptual load, thus occuring before the information reaches high-level cognition and does not require cognitive resources such as working memory to generate or maintain these representations. Thus, the representation of such possibilities is distinctly perceptual.

The present findings point to important questions about how we should understand the visual system's capacity to represent different kinds of perceptual "possibilities", and how this may relate to the representations of possibilities in higher-level cognition. In the cognitive domain, a unifying set of principles and mechanisms has been argued to be central to the different instances of possibility representation (Phillips & Hecht, 2025; Phillips & Knobe, 2018; Phillips, Morris, Cushman, 2019). In the perceptual domain, amodal completion has been explained by basic Gestalt principles of perceptual organization (e.g., good continuation, proximity, minimum principle; Michotte et al., 1991; Gerbino, 2020). To what extent similar principles underlie the perception of possible whole objects based on just their disconnected parts (Guan & Firestone, 2020, Guan, et al., 2020) remains to be tested. However, in both of these visual phenomena, the perceptual system generates possible perceptual entities that are consistent – and, critically, most *likely* – given the sensory stimulation. Intriguingly, this, at a broad level, relates to the literature on cognitive possibilities, where it has been argued that possibilities are generated on the basis of how *likely* they are to occur (Phillips, Morris, Cushman, 2019). Thus, even if the representations of perceptual and cognitive possibilities are separable, as shown in the present study, they may share some broad, general principles.

Another related question concerns whether it is actually appropriate to treat such perceptual inferences as resulting in genuine representations of *possibilities*. There has been a lively debate in the cognitive and developmental literatures about the requirements for a representation to count as a genuine representation of possibility, rather than merely a representation involving uncertainty or a representation of actuality that may be incorrect (Cesana-Arlotti, Varga, & Téglás 2022; Leahy & Carey, 2020; Phillips & Kratzer, 2024; Téglás, Girotto, Gonzalez, & Bonatti, 2007). Whether the visual system's inferences about possible shapes meet these standards remains an important and open question.

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