Past Experience and Meaning Affect Object Detection:

A Hierarchical Bayesian Approach

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Abstract

For human perceivers, object perception seems immediate and unambiguous. Following the Gestalt reaction against Structuralism over 100 years ago, it was long held that serial feedforward processing could account for object perception and that past experience and object meaning played no role because these were assumed to be activated only after objects were detected. We now know that this approach is inadequate: Our systematic investigation of past experience effects has revealed that object perception entails dynamic feedforward and feedback interactions between low- and high-level brain regions. Our research has shown that object semantics (meaning) as well as object shape are activated early in the course of object perception and that semantic activation initiated by a word can facilitate object detection. Finally, we have found that brain regions traditionally thought to be involved in explicit memory play a role in object detection. In this chapter, our work examining how past experience and meaning affects object detection is reviewed and integrated with current research from other laboratories. My goal is for this review to serve as a springboard for research aimed at a deeper understanding of the dynamical interactions involved in object perception.
I. Introduction

For human perceivers, object perception seems immediate and unambiguous. Following the Gestalt reaction against Structuralism over 100 years ago, it was long held that serial feedforward processing could account for object perception and that past experience and object meaning played no role because these were assumed to be activated only after objects were detected. We now know that this approach is inadequate: Our systematic investigation of past experience effects has revealed that object perception entails dynamic feedforward and feedback interactions between low- and high-level brain regions. Our research has shown that object semantics (meaning) as well as object shape are activated early in the course of object perception and that semantic activation initiated by a word can facilitate object detection. Finally, we have found that brain regions traditionally thought to be involved in explicit memory play a role in object detection. In this chapter, our work examining how past experience and meaning affects object detection is reviewed and integrated with current research from other laboratories. My goal is for this review to serve as a springboard for research aimed at a deeper understanding of the dynamical interactions involved in object perception.

A note regarding our general method: In many, but not all, of our experiments, we assess object detection via reports regarding where objects are perceived to lie with respect to a border – called figure–ground perception. Figure-ground perception is neither a process nor a stage of processing. Instead, it is one possible outcome when two regions in the visual input share a border. When figure-ground perception occurs, the border shared by the two abutting regions is assigned as the bounding contour of an object on one side only; that side is perceived as a shaped figure and, if it is familiar, it can be recognized. In contrast, the other side, lacking a bounding contour, is perceived as shapeless (at least locally) and appears to continue behind the object/figure. Other outcomes can be perceived, including interpreting the shared border as the place where two abutting surfaces meet on the same plane (as in a mosaic or tile pattern) or as the junction of two surfaces angled in depth (e.g., the two sides of a cube; Goldreich & Peterson, 2012; Kennedy, 1984; Peterson, 2003).

Assessments of figure-ground perception is a good way to assay object detection because the perceived object varies with the side to which the border is assigned. This is because different parts are defined on opposite sides of a border; the Rubin Vase-Faces in Figure 1 demonstrates this point. Therefore, figure reports indicate that the object per se, and not just its features, has been detected. Moreover, figure reports include information regarding where an object is located, at least with respect to a border. In the next section, I briefly review our original
behavioral findings revealing that past experience influences figure assignment before reviewing more recent results from experiments that made progress using a broad range of cognitive neuroscience techniques.

II. Background: Past experience is a prior for figure assignment

In the early 1990’s my students and I obtained a serendipitous finding that led to the proposal that, contrary to the serial, feedforward view in favor at the time, past experience with common objects is a prior (previously called a “cue”) for figure assignment (Peterson & Gibson, 1991; Peterson, Harvey & Weidenbacher, 1991). The serendipitous finding occurred in an experiment in which participants reported figure-ground reversals of displays like Figure 1B shown in both upright and inverted (Figure 1C) orientations. The displays were biased by Gestalt priors of symmetry and small area toward perceiving the center region as the figure; portions of common objects were suggested on the outside of the borders of the central region. For inverted displays, a center-as-figure bias was evident in observers’ figure reports but for upright displays, the outer regions were both more likely to be obtained as figures by reversal out of the center figure percept and more likely to be maintained as figures than in inverted displays. The former effect in particular strongly suggested that past experience with common objects might be a prior for figure assignment.

To directly pursue this hypothesis, Gibson and Peterson (1994; Peterson & Gibson, 1994a) created bipartite displays like those in Figure 2A in which two equal-area regions within a vertically elongated rectangular frame shared a central border. A portion of a common mono-oriented object was sketched on one side of the border: this was the critical side (the left side for half the stimuli and the right side for the other half). A mono-oriented object is
an object that is typically seen in one orientation; it has a typical upright orientation. Black/white contrast was balanced across left/right sides of the stimuli. (This is the custom whenever these stimuli are used.) Gibson and Peterson showed these stimuli for 86 ms on a medium gray background and followed them immediately with a pattern mask. Participants reported via left/right key press where the figure was located with respect to the central border. We didn’t compare figure reports for the critical side versus the complementary side because, despite our efforts to equate those regions for factors known to influence figure assignment, differences in unknown factors might remain. Instead, we compared figure reports for the critical side when the displays were presented such that the common object sketched on that side of the border was in its typical upright versus an inverted orientation (compare Figures 2A & 2B). This comparison holds constant all other known factors that might differentiate the critical side from the complementary side other than past experience. Each stimulus was seen once upright and once inverted, with orientation counterbalanced between subjects. This is our general procedure; there is very little or no stimulus repetition in our experiments. As can be seen in Figure 2C, participants were substantially and significantly more likely to perceive the figure on the critical side when the central border sketched a portion of a common object in its typical upright orientation rather than an inverted orientation. We took these results as evidence that past experience with common objects is a prior for figure assignment.

**Figure 2.** A. Sample bipartite display used by Gibson and Peterson (1994). The central border sketches a woman on the right. B. An inverted version of A. The central border now sketches a woman in an unfamiliar, inverted, orientation on the right. C. The percentage of trials on which the figure was perceived on the side of the border where the familiar configuration was sketched as a function of orientation.
Once the figure is perceived on the critical side, neurologically normal participants can recognize the common object depicted there in both inverted and upright displays. (I bet you can in Figure 2B!) So why are effects of past experience evident for upright displays and not for inverted displays? We propose that the orientation dependency arises because, by definition, these objects have been encountered less often in inverted than in upright orientations; as a consequence, it takes longer for evidence to accumulate in populations of cells responding to them when they are depicted in an inverted rather than an upright orientation (cf., Perrett, Oram, & Ashbridge, 1998). When displays are briefly exposed and masked, past experience effects are evident only when iterative interactions between these high-level cell populations and retinotopic representations of the displays proceed far enough before the mask appears. By chance alone, the critical region can be seen as figure in inverted displays. In those cases, object identification can be completed after figure assignment.¹

As a first step in investigating whether past experience was a figural prior, it was important to test its effects in isolation. Accordingly, in Gibson and Peterson’s (1994) experiments, none of the classic Gestalt figural priors (also called “cues”) such as symmetry, convexity, small area, enclosure, and surroundedness were present in the displays. Peterson and Gibson (1994a) took the next step by testing whether past experience effects were evident when the classic figural prior of symmetry was independently manipulated on the same or the opposite side of the border. A subset of the upright displays we used is shown in Figure 3; inverted displays were also presented. Peterson and Gibson showed brief masked exposures ranging from 14 – 100 ms and investigated when effects of symmetry and of past experience could first be measured as well as how they were combined. It was important to conduct this experiment for two reasons: First, based on the previously-described results, it could be hypothesized that past experience is recruited later than classic figural priors and only when they fail to support figure assignment. Second, many theorists assumed implicitly or explicitly that if past experience were to influence figure assignment, it would necessarily dominate the classic Gestalt priors; and that chaos would ensue because people with different experiences would perceive radically different objects.
Peterson and Gibson (1994a) found that effects of both symmetry and past experience were first evident in 28-ms masked exposures; neither exerted a measurable influence in 14-ms exposures. These results, showing that past experience plays a role as rapidly as the classic Gestalt prior of symmetry, ruled out the hypothesis that past experience exerts an influence only after figure assignment based on classic priors fails.

Next, consider the results relevant to the concern that past experience would necessarily dominate other figural priors. Most relevant here is the condition where symmetry favored perceiving the figure on one side of the central border and past experience favored perceiving the figure on the other side (the condition shown in the upper right quadrant of Figure 3). For inverted versions of those displays, participants reported perceiving the figure on the side favored by past experience on only 38% of the trials (and therefore, on the symmetric side of the border on 62% of trials). Recall that when familiar configurations are sketched in inverted orientations, effects of past experience are diminished or absent, so these results were not unexpected. The crucial question was whether past experience dominates the perceived organization of upright displays. Participants reported perceiving the figure on the side favored by past experience on a significantly higher percentage of trials in upright displays (48%) than in inverted displays (and symmetric regions were perceived as figure on a concomitantly lower percentage of trials in upright displays [52%] than inverted displays). But, past experience clearly didn’t dominate symmetry. When both priors were present in upright displays, each determined figure assignment on approximately half the trials. The results obtained with upright displays strongly suggested that the symmetry prior and the past experience prior were assigned approximately the same weight. These results showed that the concern that past experience would
dominate all other figural priors was unfounded. Instead past experience is one of many priors for figure assignment, rather than the dominant one (Peterson, 1994).

Our finding that the figure was perceived on the side of the border favored by past experience on half the trials and on the side favored by symmetry on the other half the trials suggested that object detection may be determined by competition within a hierarchical Bayesian model, as discussed in the next section. Before proceeding, I note that others had previously reported results suggesting that past experience influences figure assignment using different paradigms (e.g., Rubin, 1915/1958; Schafer & Murphy, 1943). Their results were inconsistent with the feedforward Gestalt-dominated zeitgeist in the middle of the 20th century, however. Mainstream scientists reported attempts to replicate using designs (and reasoning) that differed substantially from the original; these weak replication attempts failed to show that past experience influences figure assignment (e.g., Gottschaldt, 1926; Rock & Kremen, 1957; Smith & Hochberg, 1954). Given that these were not direct replications, they are far from definitive according to the standards of modern empirical research. Nevertheless, the refutations were sufficiently convincing within the 20th century zeitgeist that the early and mid-century demonstrations of past experience effects on figure assignment were not systematically pursued (cf., Peterson, 1999a). My colleagues and I also faced opposition arising from adherence to the traditional Gestalt views. Cognitive neuroscience advancements eroded those views, but have not completely eliminated them, in part because serial feedforward processing appeals to human thinkers (Peterson & Cacciamani, 2013).

III. Competition within a Hierarchical Bayesian Model

Our results can best be explained by a hierarchical Bayesian model in which multiple hypotheses regarding objects that might be perceived on opposite sides of a border are rapidly generated at high levels, search for confirmation in lower levels, and while doing so, engage in inhibitory competition until the best fitting object is detected (Lee & Mumford, 2003). Lee and Mumford’s hierarchical Bayesian model goes beyond the biased competition model of attention (e.g., Duncan & Desimone, 1995), in that it can account for high-level influences on perception without mediation by attention. Predictions from Lee and Mumford’s hierarchical Bayesian model for object detection include: (A) high-level hypotheses regarding objects that might be perceived (i.e., candidate objects) should be generated rapidly; (B) those candidate objects should engage in inhibitory competition; and (C) evidence of inhibitory competition in object detection should be observed in low levels where border assignment is
represented as well as in high levels. Unlike extant models of inhibitory competition in figure assignment that can account for inhibitory competition between border units based on Gestalt priors implemented at low levels of the visual hierarchy (e.g., Kienker, Sejnowski, Hinton, & Schumacher, 1986; Kogo, Strecha, Van Gool, & Wagemans, 2010; Kogo & VanEe, 2015), the Bayesian hierarchical model hypothesizes competition at both high and low levels. In the remainder of this section, evidence supporting the three predictions of the hierarchical Bayesian model is reviewed.

III.A. Rapid activation of past experience.

In this section, I review evidence that hypotheses regarding objects that might be perceived on opposite sides of a border are rapidly generated. As reviewed in Section II, Peterson & Gibson (1994a) found evidence of past experience effects using 28-ms masked displays. Those data are not a definitive index of how rapidly past experience is activated because activation time is not limited to display presentation time (cf., VanRullen, 2011) and RTs were long. Sanguinetti and Peterson (2016) reported behavioral evidence for quick activation by adapting Thorpe, Fize and Marlot’s (1996; Crouzet, Kirchner, & Thorpe, 2010) rapid categorization task: Participants viewed two silhouettes on each trial, one above and one below fixation. One of the silhouettes depicted a real-world object (see Figure 4A); the other depicted a novel object (see Figures 4B & C). Their task was to saccade toward the real-world object as quickly and as accurately as possible. All of the silhouettes were created so that the figure was highly likely to be perceived on the inside: Gestalt priors of symmetry, enclosure, surroundedness, and small area favored assigning the bounding border to the inside of the silhouette. Expectation and task set also favored that interpretation. Half of the nontarget novel objects were unambiguous in that their borders suggested a novel object on both the inside and the outside; these were control novel silhouettes (Figure 4B). The other half of the nontarget novel objects were ambiguous in that a portion of a real-world object was suggested on the outside of their borders (Figure 4C). These experimental novel silhouettes were designed so that myriad priors favored the inside as the figure whereas only the single prior of past experience favored the outside as the figure. Under these conditions, we expected that the figure would be assigned to the inside of the silhouette’s borders; the outside, where the familiar configurations lay, would be determined to be shapeless ground; and participants would therefore be unaware of the familiar configurations. For all of the experiments using these stimuli, it is important that participants are not consciously aware of the familiar objects suggested on the outside of the borders of the experimental novel silhouettes. To ascertain this was the case, in every experiment, we use a thorough post-experiment questioning...
procedure. Data from the small percentage of participants who said they even might have seen something familiar on the outside of the borders of the silhouettes were not entered into the main analyses. Hence, data obtained with these experimental novel silhouettes assesses processes taking place outside of awareness.

Figure 4. Silhouettes biased so the figure would be perceived on the inside. A. Silhouettes of Real-world objects. B. & C.: Silhouettes of Novel Objects. B. Control Novel Silhouettes. C. Experimental Novel Silhouettes that suggest portions of common objects on the outside (From right to left: seahorses, palm trees, and a bell). Participants in the experiments were not aware of the objects suggested on the outside; that side was perceived as a shapeless ground to the figures on the inside.

The experimental and control novel silhouettes were carefully matched on stimulus properties such as area, symmetry, convexity, border curvature, border length, and spatial frequency (Trujillo, Schnyer, Allen, and Peterson, 2010). To the best of our knowledge, they differ from each other only in the presence versus absence of the past experience prior of a familiar configuration suggested on the outside of their lateral borders. On a Hierarchical Bayesian account, an object candidate based on the familiar configuration suggested on the outside of the experimental novel silhouettes would be generated (hypothesized) and would remain active until figure assignment was resolved. Consequently, Sanguinetti and Peterson hypothesized that when an experimental rather than a control novel silhouette was the non-target, saccades to the familiar object depicted on the other side of fixation would be slowed because the decision regarding where the target familiar object lay would be delayed until figure assignment was resolved.
Sanguinetti and Peterson’s (2016) predictions were confirmed: Saccadic RTs (SRTs), although quick, were slower when experimental rather than control novel silhouettes were non-targets (Mean SRTs = 218 ms and 212 ms, respectively). Estimates of the first moment in time when participants began to correctly perform the task in each condition, known as the minimum saccadic RT (minSRT; see Crouzet et al., 2010) are even better indices of how rapidly past experience is activated than means. MinSRTs in Sanguinetti and Peterson’s experiment were ~200 ms when experimental novel silhouettes were non-targets and ~190 ms when the control novel silhouettes were non-targets. Thus, saccadic responses to a silhouette of a familiar object that otherwise could be made in 190 ms were slowed when a familiar configuration was suggested on the ground side of the non-target silhouette. These results move the index of how rapidly candidate objects are activated to ~190 ms. Of course, additional factors influence minSRT, including decision. Hence, these results placed an upper rather than a lower limit on the time required for past experience to be activated by the experimental novel silhouettes.

**Figure 5.** A. Schematic of the task used by Trujillo et al. (2010) and Sanguinetti et al. (2014). Responses were made after the mask before the fixation point for the next trial appeared. The correct responses for the stimuli shown are “novel,” “familiar,” and “novel.” B. ERPs from Trujillo et al. recorded for the trials with experimental novel silhouettes and control novel silhouettes. The time period during which P100 amplitude was larger for experimental than control novel silhouettes is marked by a black bar near the abscissa.

Using high temporal resolution EEG recordings, Trujillo, et al. (2010) and Sanguinetti, Allen, and Peterson (2014) found that past experience was activated even earlier. They showed a superset of the novel and familiar silhouettes used by Sanguinetti and Peterson (2016) one at a time centered on a large white background to participants whose task was to report via key press whether each silhouette depicted an object that exists in the real world or a novel object (see Figure 5A). Participants responded quickly and accurately. Importantly, they were equally accurate at categorizing experimental and control novel silhouettes as novel (e.g., in Trujillo et al, 2010 Experiment 1: 97% and 95%, respectively) and their RTs were faster for experimental than control novel silhouettes.
(504 ms vs. 512 ms, respectively). Hence, there was no evidence that the real-world objects suggested on the outside of the experimental novel silhouettes caused response interference, consistent with the hypothesis that the best fitting object candidate is decided quickly. [We don’t elaborate on the RT findings here, but see Anderson, Healey, Hasher, and Peterson (2016)]. In both sets of experiments, the P100 component was higher in amplitude when participants viewed experimental than control novel silhouettes (see Figure 5B). The onset of the P100 amplitude differences was 109 ms and 106 ms in Trujillo et al. Experiments 1 and 2 respectively and 110 ms in Sanguinetti et al. Given that the two types of novel silhouettes were matched for stimulus features, but differed in whether their borders suggested a familiar configuration on the outside, the P100 differences probably index activation of past experience and consequent differential competition for figure assignment for experimental but not control novel silhouettes (see Section IIIB. below). Thus, these EEG results provide additional evidence that past experience is activated rapidly (< 106 -110 ms), as predicted on the Hierarchical Bayesian hypothesis.

III. B. Inhibitory Competition Between Object Candidates

In this section, I review evidence consistent with the Hierarchical Bayesian Model’s proposal that that candidate objects engage in inhibitory competition before the best fitting object is detected. Computational models have long instantiated figure-ground assignment as inhibitory competition between hypothetical border assignment units (e.g., Grossberg, 1994; Jehee, Lamme, & Roelfsema, 2007; Kienker, et al, 1986; Kogo & VanEe, 2015; Roelfsema, Lamme, Spekreijse, & Bosch, 2002). In 2000, Zhou, Friedman and von der Heydt put the hypothetical border assignment units on firmer ground by identifying neurons in monkey visual cortex that coded border ownership. But Zhou et al.’s results did not speak to inhibitory competition. Vecera and O’Reilly (1998, 2000) extended Kienker et al.’s model to account for Peterson et al.’s (1991; Gibson & Peterson, 1994; Peterson & Gibson, 1991, 1993, 1994a) effects of past experience by using feedback from high-level neurons to increase the activity of feature units lying on the side of the border where the familiar configuration lay; these feature units in turn biased associated border assignment units to win the inhibitory competition (but see Peterson, 1999b). None of the models implemented competition between candidate objects; competition was assumed to occur between border units.

As an alternative, Peterson, de Gelder, Rapcsak, Gerhardstein, and Bachoud-Lévi (2000; see Peterson & Skow-Grant, 2003, for a review) proposed that in addition to competition between local, low-level, border units figure–ground perception entails inhibitory competition between object candidates that might be perceived on
opposite sides of a border. Peterson and Kim (2001) were the first to report behavioral evidence in support of this hypothesis; in doing so, they were the first to report behavioral evidence in support of the hypothesis that inhibitory competition mediates figure assignment. They hypothesized that, if the familiar configuration prior on the outside of the lateral borders of *experimental novel silhouettes* like those in Figure 4C engaged in inhibitory competition for border ownership but lost the competition, then responses to objects evoked by the familiar configuration should be suppressed. Accordingly, Peterson and Kim presented either a *control* or an *experimental novel silhouette* before line drawings that depicted either well-known common objects or novel objects. Participants’ task was to press a key to indicate whether each line drawing portrayed a real-world object or a novel object. Line drawings of novel objects were included so participants had to make a decision before making their response. Half of the line drawings of real-world objects followed an *experimental novel silhouette* that suggested the same basic level object on the outside; the other half followed a *control novel silhouette*. Because we were testing whether competition occurred between object candidates rather than between border assignment units, the contours of the line drawings of real-world objects differed from those of the preceding experimental silhouette. As predicted if the resolution of figure-ground perception involves inhibitory competition, Peterson and Kim’s participants took longer to correctly categorize line drawings as depicting real-world objects when they followed an *experimental* rather than a *control novel silhouette*.

Because competition takes time (e.g., Brooks & Palmer, 2011; Peterson & Enns, 2005; Peterson & Lampignano, 2003), Peterson and Skow (2008) attempted to separate response slowing due to competition per se from response slowing due to suppression of the object candidate that lost the competition. To test for slowing due to competition and not suppression of the losing object candidate, they included a condition where the line drawings of real-world objects followed *experimental novel silhouettes* that suggested an object from a *different superordinate category* (natural/artificial) on the outside (as well as the conditions tested by Peterson and Kim). They found that the experimental minus control difference was smaller in this new condition than in the condition when the line drawings portrayed objects from the same basic level category as the object suggested on the ground side of the *experimental silhouette* (i.e., the condition tested by Peterson and Kim). In other words Peterson and Skow’s results provided clear evidence both for inhibitory competition and for suppression of responses to object candidates that lose the competition to be perceived as the figure. Both Peterson and Kim (2001) and Peterson and Skow (2008) observed evidence of the suppression of the losing object candidate when the onset asynchrony between the silhouette and the line drawing was short and only in fast response times, suggesting that competition-induced
suppression is short lived. These behavioral results provide evidence consistent with the hypothesis that figure assignment in experimental novel silhouettes is resolved by inhibitory competition between object candidates -- one an enclosed symmetric object on the inside of the silhouette, the other a common object on the outside.

The findings reviewed so far are consistent with an inhibitory competition model, but they don’t provide direct evidence that figure assignment -- our assay of object detection -- entails inhibitory competition. Activity in the EEG alpha band has been linked to functional inhibition in the brain (e.g., Foxe & Snyder, 2011; Jensen & Mazaheri, 2010; Klimesch, 1996; Mathewson et al., 2011; Payne & Sekuler, 2014), and it has been proposed that increased alpha power reflects increased inhibition. Consequently, in order to obtain direct evidence for inhibitory competition in figure assignment, Sanguinetti, Trujillo, Schnyer, Allen, and Peterson (2016) analyzed EEG alpha power in real-time while participants viewed experimental and control novel silhouettes. They observed more alpha power while participants viewed experimental than control novel silhouettes in three experiments. This real-time difference in alpha activity was evident for up to ~200 ms post-stimulus onset. This is the time period where others have shown figure-ground perception occurs (e.g., Heinen et al, 2005; Lamme, Rodriguez-Rodriguez, & Spekreijse, 1999; Sanguinetti and Peterson, 2016; Neri & Levi, 2008; Zhou, Friedman, & von der Heydt, 2000; Zipser, Lamme, & Schiller, 1996). Thus, Sanguinetti et al.’s (2016) results were the first to show via a real-time index of neural activity that figure assignment is resolved by inhibitory competition. Furthermore, given that the presence of a familiar configuration on the outside of the experimental novel silhouettes is what occasions the greater competition in experimental than control novel silhouettes, Sanguinetti et al.’s (2016) results support the conclusion that competition occurs between candidate objects in addition to between border assignment units.

**III. C. Inhibitory competition occurs across hierarchical levels**

In this section, I review evidence consistent with the Hierarchical Bayesian proposal that multiple hierarchical levels are engaged in inhibitory competition across levels of the visual hierarchy. To address this question, Salvagio, Cacciamani, and Peterson (2012) moved away from tasks assessing inhibition of the object candidate suggested on the outside of the experimental silhouette borders. Instead, they tested whether performance along a small portion of the silhouette edge (smaller than an individual part) revealed evidence of greater suppression on the ground side of experimental than control novel silhouettes. Their participants engaged in a difficult orientation discrimination task regarding a briefly exposed (100 ms) small dim bar that was presented close
to the silhouette edges randomly on the left or the right side, on either the figure or the ground. The familiar configurations suggested on the ground side of the experimental novel silhouettes were evident globally (the silhouettes were approximately 5° of visual angle high); hence, the differences between the two types of silhouettes could be detected only in high-level brain regions where neurons have large receptive fields. A schematic of the conditions tested is shown in Figure 6.

Figure 6. Outline drawings representing the conditions tested by Salvagio et al. (2012). Their participants viewed either black silhouettes on a white backdrop or white silhouettes on a black backdrop. The tilted bar appeared equally often inside and outside the closed silhouette borders (i.e., on the figure and the ground, respectively). Experimental and control novel silhouettes were presented equally often. The common objects suggested on the outside of the experimental novel silhouettes in this Figure are snowmen (top) and pigs (bottom). The fixation point was marked by a cross in the center of the silhouette. Target bars appeared equally often above and below fixation, equally often inside and outside the silhouette borders and equally often on the left and right sides (only targets shown to the left of fixation are illustrated here.)

Performance was worse for targets located on the ground side of the borders of experimental than control novel silhouettes, as hypothesized if greater inhibition is applied on the ground side when there was more competition from the familiar configuration suggested there. Performance was equivalent for targets shown on the figure side of the two types of silhouettes, even though the locations of targets on figures versus grounds were separated by only 0.6° of visual angle. At the retinal eccentricity (2.6°) of the borders of the displays used by Salvagio et al, only V1 or V2 neurons have receptive fields small enough (<2°) to account for such fine localization of ground suppression (Bles, Schwarzbach, De Weerd, Goebel, & Jansma, 2006). Thus, these results extend previous evidence for competition-induced inhibition arising from the possibility of fitting a familiar object on the outside of the silhouette borders to low levels in the visual hierarchy, consistent with a Hierarchical Bayesian prediction that hypotheses identified at high levels compete at low as well as high levels in the visual hierarchy. Furthermore, the results are inconsistent with the view that more attention was summoned to the figures in the
Experimental novel silhouettes in order to resolve the greater competition across their borders than the borders of control novel silhouettes. Had that been the case, orientation discrimination performance should have been better for targets on the figure side of experimental than control novel silhouettes. Therefore, these results are consistent with the Hierarchical Bayesian hypothesis that high-level influences on perception are not necessarily mediated by attention. These results also refute an attention explanation of the P100 differences reported by Trujillo et al. (2010; Sanguinetti, et al. 2014).

Using fMRI, Caccimani, Scalf, & Peterson (2015) sought converging evidence that inhibitory competition occurs throughout the visual hierarchy by testing whether greater inhibition of the ground side of experimental than control novel silhouettes is evident in reduced neural activity in early visual areas (EVAs) where receptive fields encompass only part of the silhouette, not the whole silhouette. Cacciamani et al.’s participants did not discriminate the orientation of target bars shown near the silhouette borders. Instead, they engaged in a difficult search task at fixation while the silhouettes were presented in the periphery. Participants searched for lowercase letters (a, b, or c) embedded in a 4 Hz stream of digits (0-9) and ASCII symbols (#, %, $, *) presented centrally; they were instructed to ignore the silhouettes. Cacciamani et al. found that activity in regions of interest (ROIs) corresponding to silhouette ground regions in V2 and V4 was significantly reduced for experimental compared to control novel silhouettes, consistent with the proposal that inhibitory competition occurs in both V4, where receptive fields (RFs) were large enough to encompass the familiar configurations suggested on the ground sides of their stimuli, and in lower-level V1/V2, where RFs are much smaller. Like Salvagio et al.’s results (2012), these results are consistent with feedback from higher levels in the visual hierarchy where the familiar object candidate is generated.

Cacciamani, Skocypec, Flowers, Perez, and Peterson (2019) replicated Cacciamani et al. ’s (2015) results in V2 and V4, and extended them by adding a third type of stimulus with straight edges on all four sides, unlike the articulated borders of the experimental and control novel silhouettes. Although control novel silhouettes constitute excellent controls for experimental novel silhouettes because they are matched on low level factors such as border length, area, symmetry convexity, they cannot provide a baseline index of ground suppression when articulated borders are absent. Cacciamani et al. (2019) reasoned that straight-edge silhouettes could provide such an index and that including them would allow a test of whether greater inhibitory competition resulted in below baseline suppression of activity on the ground side of experimental novel silhouettes. [Cf. Likova and Tyler (2008) for evidence of ground suppression when straight edges separate a motion-generated figure and ground.
BOLD responses measured by Cacciamani et al. (2019) indicated that activity on the ground side of experimental novel silhouettes was suppressed below activity on the ground side of control novel silhouettes, replicating Cacciamani et al. (2015), but not below baseline. Instead, neural activity on the ground side of experimental novel silhouettes was statistically higher than baseline ground suppression. Activity on the ground side of control novel silhouettes was higher still. Why would neural activity on the ground side of control novel silhouettes be so high? This pattern can be explained by prediction error within a Hierarchical Bayesian Model: Because the articulated borders of the control novel silhouettes could be decomposed into parts, one or more high-level object candidates that might be present on their outsides were probably generated. Processes matching those hypothesized objects to the input would produce much higher error for control novel silhouettes than for straight-edge silhouettes because the latter would generate few hypotheses regarding candidate objects on the outside. Therefore, the substantially higher activity on the ground side of control novel silhouettes than straight-edge silhouettes may be attributed to substantially higher prediction error. BOLD responses were also higher on the ground side of experimental novel silhouettes than straight-edge silhouettes. We propose that is because unconsciously matching the high-level hypothesis that a familiar object was present along the border produced low error (albeit some error because this particular version of the familiar object had not been seen before). These results are interesting because the vast majority of the evidence for predictive models concerns consciously perceived objects. Yet prediction is assumed to occur outside of awareness (e.g., Panicello, Cheung, & Bar, 2013); these results support that assumption for predictions regarding objects. We submit that competition-induced suppression also contributed to the lower activity on the ground side of experimental than control novel silhouettes. In future research it will be important to tease apart the contributions of prediction error and competition-induced suppression to activity in the ground ROIs of the experimental novel silhouettes.

The experiments reviewed in this section extend evidence of inhibitory competition in object detection to low levels of the visual hierarchy, consistent with the hypothesis derived from Lee and Mumford’s Hierarchical Bayesian Model that competition between candidate objects (i.e., object hypotheses) occurs across levels of the visual hierarchy (see also Peterson and Cacciamani, 2013; Nadel and Peterson, 2013). The familiar configurations that lose the competition to be detected as objects are sketched globally along the borders of our stimuli, yet evidence for inhibition is found in low-level areas.
IV. Interim Summary

The experiments reviewed so far showed that the shape of previously seen objects serves as a prior for figure assignment. They also support the hypothesis that inhibitory competition within a Hierarchical Bayesian model is the mechanism of object detection by showing that hypotheses regarding objects that might be perceived on opposite sides of a border (A) are rapidly generated at high levels, (B) are tested across hierarchical levels, and while doing so, (C) engage in inhibitory competition. In Section V, I review evidence that the meaning of objects as well as their shape is activated during object detection rather than afterwards, as assumed in traditional theories. Evidence that the prior presentation of the basic level name of an object can enhance object detection is also reviewed there. Finally, in Section VI, I address questions concerning whether past experiences relevant to figure assignment originate in high-level brain regions.

V. Beyond Shape: Object Detection Entails Access to Meaning

One question raised by the evidence reviewed so far is: Is the meaning of candidate objects as well as their shape considered during object detection? In other words, does activation spread beyond shape exemplars to semantics? Peterson and Kim’s (2001; Peterson & Skow, 2008) evidence that responses were slower to line drawings depicting different objects in the same basic level category as the object suggested on the ground side of a silhouette suggests that semantics may have been activated at a basic level, although structural similarity rather than semantics may account for their results. Peterson, Cacciamani, Mojica, and Sanguinetti (2012) took the additional step of investigating whether the superordinate category of objects that are potentially present in a scene is activated prior to figure assignment. They asked participants to categorize target words as naming either natural or man-made (artificial) objects. The words were shown one at a time following experimental novel silhouettes; the target words denoted either an object in the same basic level category as the familiar object suggested on the ground side of the silhouette (SO) or a different object (DO; see Figure 7). When the words denoted a DO, that object was either in the same superordinate category (DO-SC) or a different superordinate category (DO-DC) as the object suggested in the ground side of the preceding silhouette; the superordinate categories were natural versus artificial objects. Peterson et al. reasoned that if word categorization response times differed as a function of whether the object suggested on the ground side of the preceding silhouette was from the same or a different superordinate category, that would indicate that superordinate category knowledge is activated for object candidates that compete for figural status but
ultimately lose the competition. This conclusion is possible both because the word categorization task involves making a judgment regarding a high-level conceptual category, and because conceptual knowledge necessarily mediates any effects of the prior presentation of an object on the response to a word (e.g., Dehaene, et al. 1998; Jackendoff, 1983). Peterson et al. found that word categorization RTs were statistically and substantially faster in the SO and DO-SC conditions than in the DO-DC condition.

![Figure 7. Sample stimuli from the Same Object (SO) condition (left column stimuli), DO-SC (Different Object, Same Category) condition (center column of stimuli), and DO-DC (Different Object, Different Category) condition (right column of stimuli) for both natural (top row) and artificial (bottom row) words. “Category” refers to the superordinate categories of natural versus artificial objects (human made). The borders of the silhouettes in the top row suggest portions of hands, maple leaves and axes from left to right. The borders of the silhouettes in the bottom row suggest portions of anchors, umbrellas and seahorses from left to right.](image)

Taken alone, however, Peterson et al.’s (2012) study cannot answer the question of whether superordinate category membership semantics are activated for an object suggested on the ground side of a border: This is because the borders of the experimental novel silhouettes that suggested natural objects on their ground sides were more curvilinear than those that suggested artificial objects on their ground sides. Therefore, participants’ responses may have been primed by features of the borders of the figures themselves (curvilinear → natural; rectilinear → artificial) rather than by the semantics of the candidate objects suggested on the ground side of the borders.

To separate effects attributable to border features per se from those attributable to the candidate objects suggested on the ground side of the borders, Cacciamani, Mojica, Sanguinetti, and Peterson (2014) presented the silhouettes in both upright and inverted orientations. The features of the borders (curved vs. straight) remain the same over the change in orientation from upright to inverted. Therefore, if border features per se were responsible for the pattern of RTs observed by Peterson et al, the same pattern should be obtained regardless of the orientation of
the silhouette preceding the word. In contrast, more time is required for the population of cells responding to the familiar configuration to reach threshold for inverted displays (e.g., Perrett, et al, 1998) Therefore, Cacciamani et al. reasoned that it would also take longer for the superordinate category to be activated for inverted displays and this additional time might exclude semantic priming effects, just as it excluded effects of past experience on figure assignment (see Section II). They reasoned that if activation of the semantics of the ground side candidate objects was responsible for the faster response times in the same- versus different-category conditions tested by Peterson et al., then that pattern should be replicated for upright displays but not for inverted displays. Cacciamani et al. observed the same pattern of results reported by Peterson et al (2012) for upright displays only. Thus, together, these two articles provide behavioral evidence that superordinate category meaning is activated for object candidates that are considered, but rejected, in the course of object detection. In both sets of experiments, the silhouettes appeared at fixation at a fixed, and therefore an expected, time after trial onset. Flowers and Peterson (2018) replicated those results with silhouettes presented in peripheral locations at unpredictable times. The neural substrate for these semantic priming effects may lie in the clusters of category specific representations in inferior temporal cortex (Kriegeskorte, et al, 2008), but they clearly assay meaning in addition to featural differences between natural and artificial objects.

Peterson et al. (2012) and Cacciamani et al. (2014) assumed that the priming results they obtained indexed a prospective influence on the word targets from the silhouette primes -- that meaning activated for the object candidates in the course of object detection influenced responses to the target words. It has been proposed, however, that primes may be retrospectively processed for information relevant to processing the target (e.g., Masson & Bodner, 2003, but see Bodner & Masson, 2014). Using EEG, Sanguinetti et al. (2014) sought converging evidence that meaning was activated in real-time while observers viewed the silhouettes. They recorded EEGs while participants viewed brief exposures (175 ms) of experimental and control novel silhouettes intermixed with silhouettes of real-world objects (see Figure 4) and reported via key press whether each silhouette depicted a real-world or a novel object. Thus, the silhouettes themselves were the targets. Sanguinetti et al. were particularly interested in the N400, a negative going component of the event-related potential (ERP) evident ~400 ms after stimulus onset. The N400 is taken as a robust indicator of semantic processing for a variety of stimuli including objects (for review, see Kutas & Federmeier, 2011).
Sanguinetti et al. (2014) based their study on experiments reported by Voss, Schendan, and Paller (2010), who found that the N400 was reduced when meaningful, but not meaningless, line drawings were repeated; these are N400 repetition effects. Therefore, Sanguinetti et al. repeated each silhouette after four to seven intervening stimuli and compared the N400 amplitude on the first to the second presentation. They observed N400 repetition effects for silhouettes that depicted meaningful real-world objects (like those in Figure 4A) and for experimental novel silhouettes that suggested meaningful objects on the ground side of their borders (Figure 4C), but not for control novel silhouettes that did not suggest meaningful objects on the ground side (Figure 4B). Sanguinetti et al.’s results provided the first neurophysiological evidence that meaning is activated for object candidates that compete for figural status but ultimately lose the competition and consequently, are not consciously perceived. In a second experiment, Sanguinetti et al. repeated the object concept, but not its shape by presenting a brief (50 ms) masked exposure of a word that denoted either the basic-level object suggested on the ground side of the experimental silhouettes or a different object from a different superordinate category. They observed N400 repetition effects while observers viewed the silhouettes in the former but not the latter condition, showing that repetition of meaning bridges across modality – from words to objects.

In addition to supporting the hypothesis that meaning is activated for candidate objects in real-time during object detection, Sanguinetti et al.’s (2014) Experiment 2 raised the question of whether semantic activation initiated by word primes can facilitate object detection. We are not the first to explore this question (see Lupyan & Spivey, 2008; Lupyan & Thompson-Schill, 2012; Lupyan & Ward, 2013), although others have operationalized object detection differently. For instance, Lupyan and Ward (2013) defined object detection as the point in time when line drawings of familiar objects emerged from Continuous Flash Suppression (CFS). They investigated whether this time point was shifted earlier when the basic level name of the object was presented audibly before the masking sequence. Lupyan and Ward found that objects emerged from CFS earlier when the same versus a different object name was presented prior to the masking sequence. They ruled out guessing as an explanation, and showed that the effects depended on the detection of object features. In my view, detecting the features of an object does not amount to object detection, however. Participants could have detected fragments of the object’s borders rather than the object per se. Figure assignment better assays object detection because simply detecting border features is insufficient; the assignment of the border to one side or the other is necessary for an object to be perceived.
Therefore, the question of whether semantic activation initiated by word primes can facilitate object detection remained unanswered when we embarked on these experiments.

Skocypec and Peterson (2018) tested whether semantic activation initiated by a word prime facilitates figure assignment – our index of object detection. To do so, we presented a word for 500 ms before bipartite test displays in which a portion of a familiar configuration was suggested on one side of the central border (balanced for left/right location and black/white contrast as usual). Participants reported whether the figure lay on the left or right side of the central border. The words were either the basic-level name of the object suggested on one side of the central border or the name of an object from a different superordinate category (matched for word frequency and length). A trial sequence is shown in Figure 8. To be certain participants processed the meaning of the word, we asked them to report via key press whether each word denoted a natural or an artificial object; they could take up to 1.5 s to respond, although most participants responded much faster. A 200-ms delay occurred after their response and before the bipartite display which was shown for 90 ms in an upright or an inverted orientation and followed by a mask.

**Figure 8.** Trial sequence used by Skocypec and Peterson (2018). At the beginning of each trial, a word was shown for 500 ms. Participants were given up to 1500 ms to categorize the word as denoting a natural or artificial object. A 200-ms delay intervened between their response and the onset of a bipartite test display, which remained in view for 90 ms and was followed by a pattern mask. Participants were given up to 3 s to report whether they perceived the figure on the left or the right side of the display.

As expected if semantics facilitate object detection, observers reported the figure on the side of the border where the familiar configuration lay more often when the word prime named that object rather than a different object. This pattern was evident with both upright and inverted bipartite displays. Recall from Section II that we
attribute the orientation-dependency of past experience effects to the longer time required for evidence to accumulate in populations of cells responding to familiar objects when they are depicted in an inverted rather than an upright orientation (cf., Perrett, et al, 1998). Therefore, these priming results to suggest that the rate of evidence accumulation in the population of cells coding the familiar object candidate is increased by the prior presentation of its basic-level name. Thus, not only are semantics activated by the object candidates, in addition, the prior activation of semantics can facilitate the likelihood of detecting an object on the side of a border where a related familiar configuration lies. These results show that semantic activation initiated by a word can facilitate object detection indexed by figure assignment, a task we argue constitutes a superior assay of object detection than previous measures. The neural substrate for Skocypec and Peterson’s (2018) behavioral results could either be in the inferior temporal cortex (IT) or in occipitotemporal, parietal, or frontal cortices where Kumar, Federmeier, Fei-Fei, and Beck (2017) found similar neural patterns of response to words and pictures of scenes.

VI. How high is high?

An abiding question concerns whether high-level influences on visual perception originate in brain regions dedicated to vision or whether brain regions dedicated to memory can exert an influence on visual perception. Of course, merely asking the question assumes that there exist brain regions and neural mechanisms dedicated to processing vision or memory, and this assumption can be challenged. This question can be phrased in terms relevant to the Hierarchical Bayesian Model, as “How high in the hierarchy are the regions that generate object candidates?”

My colleagues and I examined whether the perirhinal cortex (PRC) of the medial temporal lobe (MTL) plays a role in object detection. The PRC is a brain region that lies beyond the traditional visual pathway, and was long thought to be involved in declarative memory only, not in perception. Beginning in 1999, some scientists presented evidence they took to indicate that the PRC play a role in visual perception (e.g., Barense, Gaffan, & Graham, 2007; Buckley, Booth, Rolls, & Gaffan, 2001; Murray & Bussey, 1999). Those studies showed, for instance, that damage to the MTL including the PRC impaired the ability to discriminate between objects composed of common features arranged in different configurations. These results led to the hypothesis that the PRC supports performance on memory and perception tasks that require the processing of configurations of features rather than single features (Bussey et al. 2002; Barense et al. 2005, 2007; Bartko et al. 2007; Barense, Rogers, et al. 2010): In previous investigations, PRC contributions to perception tasks were gauged with visual odd-one out tasks in which
participants viewed seven objects comprising three pairs and one un-paired object (the odd-one out). All the objects were visible simultaneously, so on the face of it, this task was not a memory task. But simultaneous presentation alone doesn’t guarantee that a task assesses perception. Indeed, the odd-one out task requires participants to remember which objects in which locations they have already paired and which one remains unpaired. The memory involved is not declarative memory, but it is working memory.

In order to explore the role of the PRC in object detection, per se, Barense, Ngo, Hung, and Peterson (2012) investigated figure assignment. They used upright and inverted bipartite test displays like those in Figure 2 (and also in the top row of Figure 9), supplemented with Part-Rearranged Novel Test Displays like those in the bottom row of Figure 9. In Part-Rearranged Novel Displays the spatially rearranged parts of a familiar configuration are sketched on one side of the central border. These critical regions in Part-Rearranged Novel Displays depicted novel objects; they bore little or no resemblance to familiar objects (ascertained by pilot testing). Peterson et al. (1991; Gibson & Peterson, 1994) had previously used Part-Rearranged Novel Displays to examine whether past experience effects on figure assignment in non-brain damaged participants were mediated by familiar parts or by familiar configurations. Their participants perceived the figure on the critical side of the border substantially and significantly more often when it suggested an intact upright familiar object (as in the top row of Figure 9) rather than its part-rearranged counterpart (as in the bottom row of Figure 9). Thus, in the participants tested previously, familiar parts were not sufficient for past experience effects on figure assignment; effects of past experience on figure assignment were evident only when familiar configurations were present (cf., Peterson et al, 1998; Peterson, et al, 2000). Given the deficits shown by patients with damage to the PRC of the MTL, Barense et al. tested whether PRC damage weakens effects of familiar configurations on figure assignment and/or releases effects of familiar parts. Such a finding would provide strong support for the hypothesis that the PRC plays a role in object detection when access to configurations, rather than to individual parts or features, is key.
Figure 9. Sample stimuli used by Barense et al. (2012). The critical regions of the sample stimuli in the top row depict the intact configuration of common objects; from left to right: a guitar, a woman, and a table lamp. The critical regions of the stimuli in the bottom row depict versions of these objects with their parts (delimited by successive minima of curvature) spatially rearranged. For display purposes, the critical regions here are always shown in black and on the left (this was fully counterbalanced in the experiment).

Barense et al. (2012) showed these displays to two individuals with bilateral MTL damage that included the PRC and the hippocampus (HC) as well as to two control patients with selective HC damage and 30 healthy volunteers. It is rare for PRC damage to be observed without hippocampal damage. And indeed, the individuals with PRC damage tested by Barense et al. (2012) also had HC damage. Comparing their data to data obtained from individuals with selective HC damage provides a means to separate out deficits due to PRC damage. Both healthy controls and controls with selective HC damage showed a large effect of past experience on figure assignment. They perceived the figure on the critical side of the border substantially and significantly more often when it suggested an intact familiar configuration rather than a novel configuration composed of spatially-rearranged parts. Effects of familiar configuration on figure assignment are graphed in Figure 10 as the difference between the percentages of trials on which participants reported the figure on the critical side of the border when it suggested a familiar object versus a novel object. In contrast, individuals with damage to the PRC as well as the HC reported perceiving the figure on the critical side of the border (a) less often than controls in displays suggesting an Intact Familiar configuration, indicating that damage to the PRC weakens effects of familiar configurations and (b) more often than controls in Part-Rearranged Novel Displays, indicating that damage to the PRC releases effects of part familiarity on figure assignment that were not observed in individuals with an intact PRC. As can be seen in Figure 10, effects of familiar configuration on figure assignment were diminished in PRC-damaged individuals. This finding suggests that the PRC played a role in the previously reported effects of familiar configuration on figure assignment. The
PRC is a high-level structure indeed; it lies beyond the anterior inferior temporal lobe, the traditional end of the ventral visual processing pathway. And recall that the PRC was previously viewed as a structure specialized for declarative memory rather than perception.

Figure 10. The effect of familiar configuration on figure assignment shown as the difference between the percentage of trials on which participants reported the figure on the critical side of the border when a familiar configuration versus a part-rearranged novel configuration composed of the same (familiar) parts was suggested there. The first column shows the data from 30 age-matched controls (Controls); the second column shows the data from two individuals with selective to the hippocampus (HC cases). It is clear that these participants show substantially larger effects of familiar configuration on figure assignment than effects of familiar parts. The remaining columns show the same difference scores for two individuals with PRC damage (MTL 2 and MTL 3); each was tested twice. The familiar minus novel configuration difference score was significantly reduced for all administrations in the MTL cases compared with the non-brain-damaged controls as indicated by asterisks. The familiar minus novel configuration difference scores were reduced in the MTL cases because of both decreased figure responses to the intact familiar configurations and increased figure responses to part rearranged novel displays.

How might the PRC be involved? Barense et al. (2012) reasoned that the role of the PRC might be to modulate lower-level responses to familiar parts as a function of the familiarity of the configuration they’re part of—to reduce the familiarity response to parts arranged in a novel configuration or to enhance the familiarity response to parts arranged in a familiar configuration. This proposal requires that the intact PRC detects the difference between intact familiar configurations and novel configurations composed of familiar parts, which would be evident in a differential response to these two types of configurations. The proposal also requires that the PRC modulates lower-level part familiarity responses.

Peterson et al. (2012; Cacciamani et al., 2017) found support for the entailments of this modulation proposal using fMRI. They showed participants three types of figures in an event related design: (a) intact familiar configurations, (b) novel configurations composed of the same spatially rearranged familiar parts (Part Rearranged...
Novel figures), and (c) control novel figures composed of novel parts. The control novel figures were created by inverting the Part Rearranged Novel figures, on the assumption that parts of mono-oriented objects become familiar through repeated exposure in an upright orientation just like the configurations, and therefore that inverting them renders them unfamiliar. Figure 11 shows the data reported by Cacciamani et al. (2017): Activation in the left hemisphere (LH) PRC was highest for Familiar Configurations and lowest for Part-Rearranged figures (even though these two configurations were composed of the same parts); activation for the control novel figures was intermediate between the other two. It’s interesting to note that activation for the Part-Rearranged Novel figures was lower than for the control novel figures. Thus, the PRC does discriminate between a familiar configuration and novel configuration composed of the same parts. It also discriminates between the two novel configurations, one composed of familiar parts and one composed of novel parts. (We used a cluster-based analysis method that has been suggested to be vulnerable to type I error when applied in the absence of an a priori prediction about where activation should occur. Caccimani et al.’s experiment was designed to replicate our previous findings in young adults (Peterson et al., 2012). Therefore, any finding of the predicted replication is unlikely to reflect type I error and meets recent demands for reproducibility in psychological science (Open Science Collaboration, 2015).

Figure 11. A. Parameter estimates reported by Cacciamani et al. (2017) in the left hemisphere (LH) PRC for the Familiar Configurations (FAM) and the Part-Rearranged (PR) Novel Configurations shown as difference scores (FAM – Control) and (PR – Control). Note that the parameter estimates were calculated for each condition across the spatial extent of clusters of voxels in PRC that exhibited a significant linear pattern of activation for RVF presentation in the direction Familiar > Control Novel > Part-Rearranged Novel. These clusters were our primary dependent variable. Hence, the data in (A) are for illustrative purposes only; they are not an exact representation of the data submitted to the group level GLM analysis that produced the cluster. Error bars represent standard errors of the mean. LH, left hemisphere. B. Responses in the LH EVAs V1, V2, and V3. Responses to the control novel responses are not shown because they were used to identify the ROIs in the EVAs. The differences evident in the EVA mirror those in the PRC.
Cacciamani et al. (2017) also examined activity in the LH early visual areas (EVA) V1, V2, and V4 for differences in familiarity responses to the parts. In these regions, activation was higher for the Familiar Configuration than for the Part Rearranged Novel configurations, a pattern that echoed the PRC responses. (Responses to the control novel configurations could not be compared to the other two conditions because responses in that condition were used to define the regions of interest in the EVA.) Because the RFs of EVA neurons are more likely to encompass parts of our stimuli rather than the whole configuration, and the parts are the same in the two configurations, this pattern could represent the proposed modulation of lower level part familiarity responses by the PRC. An alternative explanation rests on the fact that the concave cusps between the parts are necessarily different and less familiar in Part Rearranged Novel configurations than in the Familiar Configurations. A functional connectivity analysis conducted by Cacciamani et al. showed evidence of a significant coupling between the PRC and V2 in the left hemisphere which favors the interpretation that the PRC modulates V2 part familiarity responses as a function of the familiarity versus novelty of the whole configuration.

The series of experiments that began with tests of individuals with damage to the PRC of the MTL led us to understand that the PRC, a brain region previously thought to subserve memory only and not perception, plays a role in object detection. Furthermore, our fMRI evidence suggests that the PRC modulates the EVA. These results provide a partial answer to the question of “How high is high?” by showing that a brain area located beyond the traditional end of the visual processing pathway mediates effects of familiar configurations on object detection (see also Nadel and Peterson, 2013).

VII. Conclusion

The systematic investigations reviewed in this chapter show that object perception entails dynamic feedforward and feedback interactions between low- and high-level brain regions, whereby familiarity and meaning play a role in object detection. While much has been done, it has only scratched the surface. There is still a great deal to do to uncover the nature of these interactions, the neural networks involved, and the role they play in object detection.
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Footnotes

1 We have also found orientation-dependent influences of past experience on figure assignment with longer displays shown for 1s – 30s (e.g., Barense et al, 2012; Peterson et al, 1991; Peterson, Peterson & Gibson, 1994b). Without masks, figures are more likely to be perceived on the critical side of both upright and inverted displays; nevertheless a substantial orientation dependency remains suggesting that figure assignment may be determined based on available evidence at some point after stimulus exposure even when masks are not used.

2 Mojica and Peterson (2014) found that symmetric regions were perceived as figures in two-region displays where past experience was not present on approximately the same percentage of trials.