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Neural evidence for competition-mediated suppression in the perception of a single object

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ABSTRACT

Multiple objects compete for representation in visual cortex. Competition may also underlie the perception of a single object. Computational models implement object perception as competition between units on opposite sides of a border. The border is assigned to the winning side, which is perceived as an object (or "figure"), whereas the other side is perceived as a shapeless ground. Behavioral experiments suggest that the ground is inhibited to a degree that depends on the extent to which it competed for object status, and that this inhibition is relayed to low-level brain areas. Here, we used fMRI to assess activation for ground regions of task-irrelevant novel silhouettes presented in the left or right visual field (LVF or RVF) while participants performed a difficult task at fixation. Silhouettes were designed so that the insides would win the competition for object status. The outsides (grounds) suggested portions of familiar objects in half of the silhouettes and novel objects in the other half. Because matches to object memories affect the competition, these two types of silhouettes operationalized, respectively, *high competition and low competition* from the grounds. The results showed that activation corresponding to ground regions was reduced for *high-* versus *low-competition* silhouettes in V4, where receptive fields (RFs) are large enough to encompass the familiar objects in the grounds, and in V1/V2, where RFs are much smaller. These results support a theory of object perception involving competition-mediated ground suppression and feedback from higher to lower levels. This pattern of results was observed in the left hemisphere (RVF), but not in the right hemisphere (LVF). One explanation of the lateralized findings is that task-irrelevant silhouettes in the RVF captured attention, allowing us to observe these effects, whereas those in the LVF did not. Experiment 2 provided preliminary behavioral evidence consistent with this possibility.

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1. Introduction

The ability to perceive objects is essential to our interaction with the world. Although it seems effortless and immediate, object perception is a computationally demanding task that requires extensive neural processing. Prior research has focused on understanding this neural processing, yet object perception is still not entirely understood. The current study aims to shed light on the neural mechanisms involved in the perception of a single object.

Previous work indicates that competitive suppressive interactions occur among representations of multiple objects shown simultaneously such that the firing rate in stimulated brain areas is lower than the sum of the responses to each item presented individually (Luck, Chelazzi, Hillyard, & Desimone, 1997; MacEvoy & Epstein, 2009; Miller, Gochin, & Gross, 1993; Reddy & Kanwisher, 2007; Reynolds, Chelazzi, & Desimone, 1999; Rolls & Tovee, 1995; Snowden, Treue, Erickson, & Andersen, 1991; Zoccolan, Cox, & DiCarlo, 2005). The reduced response is thought to result because multiple simultaneously presented items engage in inhibitory competition for representation (Moran & Desimone, 1985; Reynolds et al., 1999). Competition-mediated suppression between multiple objects has been observed in visual areas as low as V1/V2 and as high as the inferior temporal cortex (IT) via single-cell recording in monkeys (Miller et al., 1993; Reynolds et al., 1999) and functional magnetic resonance imaging (fMRI) in humans (Beck & Kastner, 2005; 2007; Kastner, de Weerd, Desimone, & Ungerleider, 1998; Scalf & Beck, 2010; see Beck & Kastner, 2009, for a review).

It has been proposed that suppressive competition underlies the perception of a single object when a border shared by two visual field regions is perceived as a boundary for the region on one side but not the other. The side to which the border belongs is perceived as a shaped object (or *figure*); the other side is perceived as a locally shapeless *ground* continuing behind the object. Computational theories of figure-ground perception implement suppressive competition between low-level edge-units, feature-units and/or image-based properties such as convexity, symmetry, and small area detected on opposite sides of a shared border (e.g., Craft, Schutze, Niebur, & von der Heydt, 2007; Grossberg, 1994; Kienker, Sejnowski, & Hinton, & Schumacher, 1986; Kogo, Strecha, Van Gool, & Wagemans, 2010; Roelfsema, Lamme, Spekreijse, & Bosch, 2002; Sejnowski & Hinton, 1987; Vecera & O'reilly, 1998). In these models, units on the winning side (the object or "figure" side) are ultimately enhanced relative to units on the losing side (the groundside). And indeed, neural evidence shows that responses to figures are enhanced relative to responses to grounds (Roelfsema et al., 2002).

Behavioral experiments using stimuli like those in Fig. 1 support the hypothesis that perceiving an object on one side of a border entails suppressive competition. These stimuli were designed so that figural/object status would be highly likely to be assigned to the inside of the bounded region (e.g., the insides were closed, symmetric, and small in area). These figures were novel objects. The amount of competition for object status was varied across two subsets of these stimuli: the borders of half the stimuli suggested a portion of a familiar, real-world object on the outside—the side that was ultimately perceived as the ground (Fig. 1B)—whereas the other half did not (Fig. 1A). Given that familiar configuration plays a role in figure assignment (see Peterson & Skow-Grant, 2003, for a review), these were *high-competition* and *low-competition* stimuli, respectively. Consistent with the hypothesis that suppressive competition is one mechanism of object perception, Sanguinetti, Trujillo, Schnyer, Allen, and Peterson

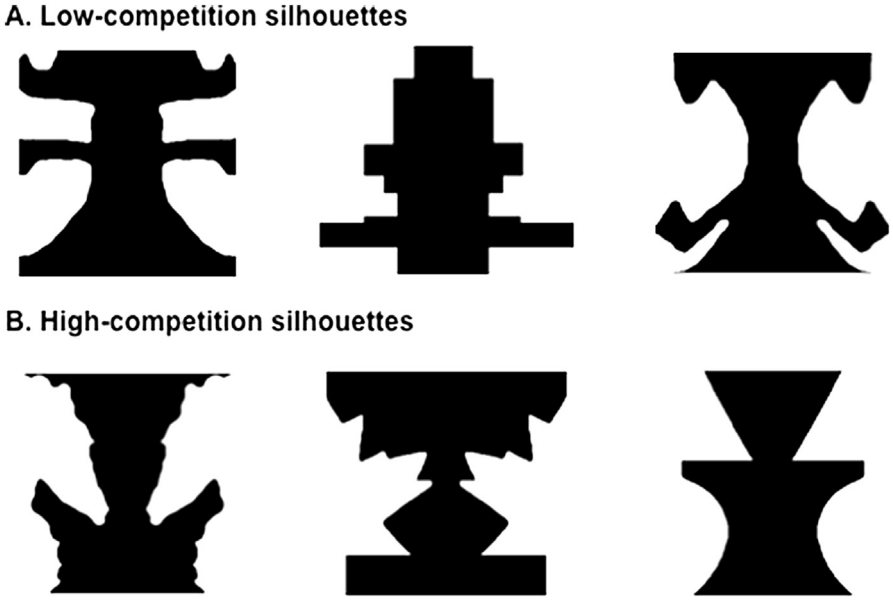

Fig. 1 – Sample novel silhouettes used in the current experiment (see also Peterson & Kim, 2001; Peterson & Skow, 2008; Salvagio et al., 2012; Trujillo et al., 2010). (A) *Low-competition* silhouettes which suggest novel, meaningless shapes on the groundsides. (B) *High-competition* silhouettes which suggest portions of familiar, real-world objects on their groundsides. The familiar objects suggested are (from left to right) seahorses, maple leaves, and table lamps.