Consciousness and Cognition 35 (2015) 330–341

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Selecting category specific visual information: Top-down and bottom-up control of object based attention

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ARTICLE INFO

Article history:
Received 17 December 2014
Revised 6 February 2015
Accepted 10 February 2015
Available online 28 February 2015

Keywords:
Object attention
fMRI
Top-down
Bottom-up

ABSTRACT

The ability to select, within the complexity of sensory input, the information most relevant for our purposes is influenced by both internal settings (i.e., top-down control) and salient features of external stimuli (i.e., bottom-up control). We here investigated using fMRI the neural underpinning of the interaction of top-down and bottom-up processes, as well as their effects on extrastriate areas processing visual stimuli in a category-selective fashion. We presented photos of bodies or buildings embedded into frequency-matched visual noise to the subjects. Stimulus saliency changed gradually due to an altered degree to which photos stood-out in relation to the surrounding noise (hence generating stronger bottom-up control signals). Top-down settings were manipulated via instruction: participants were asked to attend one stimulus category (i.e., "is there a body?" or "is there a building?"). Highly salient stimuli that were inconsistent with participants' attentional top-down template activated the inferior frontal junction and dorsal parietal regions bilaterally. Stimuli consistent with participants' current attentional set additionally activated insular cortex and the parietal operculum. Furthermore, the extrastriate body area (EBA) exhibited increased neural activity when attention was directed to bodies. However, the latter effect was found only when stimuli were presented at intermediate saliency levels, thus suggesting a top-down modulation of this region only in the presence of weak bottom-up signals. Taken together, our results highlight the role of the inferior frontal junction and posterior parietal regions in integrating bottom-up and top-down attentional control signals.

1. Introduction

Visual perception is fast and seemingly effortless. However, the ease and speed with which we see the world obscures the fact that perception requires active processing and is based on complex calculations and analyses. Given that the human brain disposes of only limited processing resources at any specific moment, it is of foremost importance to assign these resources to the currently most relevant information and to avoid wasting valuable processing capacity on irrelevant or unimportant input. The process of discriminating relevant from irrelevant information is commonly referred to as selective visual attention. In order to distribute efficiently processing resources the brain needs to decide which information is important and ought to be processed preferably. The processes involved in controlling attentional selection are often classified as

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http://dx.doi.org/10.1016/j.concog.2015.02.006

either top-down or bottom-up. While the former refers to attentional selection mainly driven by intentions and internal settings of an observer, the latter is supposed to be determined by the features of the visual stimulus. Particularly, bottom-up selection is assumed to be largely based on perceptual salience, with stimuli having a greater chance of being selected the more they stand-out with respect to the background. Since an efficient allocation of attentional resource requires a smooth interplay between bottom-up and top-down mechanisms, the two need to interact constantly.

From the perspective of top-down control, this interaction requires incorporating different bottom-up signals in situations where these may or may not fit current goals. For example, when bottom-up and top-down signals converge, a stimulus relevant for the participant's intention can be selected fast and easily when highly salient, with irrelevant information being discarded efficiently when conveyed by a weak bottom-up signal, as induced by low salient stimuli. However, when bottom-up and top-down signals convey conflicting information, one system needs to dominate the other. For instance, a highly salient bottom-up signal that is inconsistent with one's current attentional set has to be suppressed by top-down mechanisms when trying to avoid distraction.

It has been suggested that the top-down and bottom-up processes rely on differential neural networks (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Corbetta, Patel, & Shulman, 2008; Corbetta, Shulman, et al., 2002). While top-down attention is commonly assigned to bilateral superior parietal and superior frontal brain regions (i.e., the dorsal attention network), bottom-up processing is often related to inferior parietal cortex as well as the inferior frontal junction (IFJ) and anterior insula (i.e., the ventral attention network).

We here investigated the neural mechanisms underlying increased information exchange between bottom-up and top-down control. The increased information exchanged was brought about by showing pictures of bodies and buildings embedded into noise patterns of matched spatial frequency (Fig. 1). This setting enabled us to vary independently the strength of both top-down and bottom-up signals, not only by asking participants to focus on one stimulus category at a time (i.e., "is there a body?" vs. "is there a building?"), but also by manipulating parametrically the degree to which each stimulus was salient. This experimental design thereby allowed us to identify how signals emerging from the two control systems are integrated.

In particular, we focused on two extrastriate areas: (i) the extrastriate body area (EBA), located bilaterally in the posterior portion of the middle temporal gyrus, (Downing, Jiang, Shuman, & Kanwisher, 2001; Peelen & Downing, 2007) known to process human bodies in a category-selective fashion, and (ii) the parahippocampal place area (PPA, Epstein & Kanwisher, 1998), located in the posterior portion of the parahippocampal gyrus bilaterally, known to respond preferentially to scenes and buildings. As selective attention enhances activity in visual brain regions coding attended features (see Maunsell & Treue, 2006 for a review), we expected the activity of EBA and PPA to be augmented whenever participants directed their attention towards the regions' preferred category. Note that such augmented activity is not held to occur independently of the current visual input, but rather to be integrated with bottom-up information (Reynolds, Pasternak, & Desimone, 2000).

Finally, when stimulus salience was high but incompatible with an active top-down setting – e.g. participants saw a salient body whilst looking for houses – we expected to find increased neural activity in brain regions concerned with counteracting bottom-up signals or top-down settings. Potential target regions include the IFJ, corresponding to the posterior end of the inferior frontal gyrus, and parietal cortex (Corbetta et al., 2002, 2008). Both regions have been suggested to act as an interface between the dorsal and ventral attention systems or alternatively to serve as a circuit breaker, interrupting ongoing processes in the dorsal attention system based on bottom-up signals.

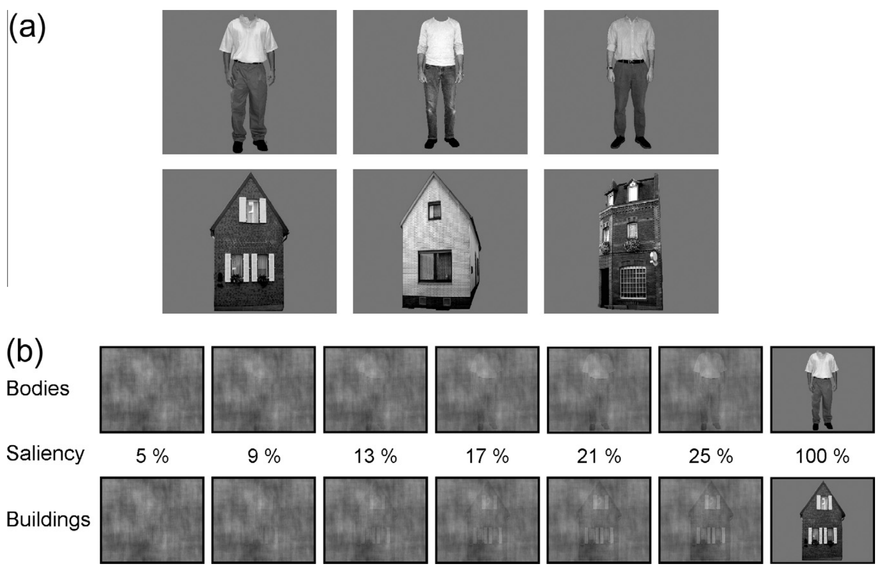

Fig. 1. (a) The three human bodies and the three buildings used for the present experiment. (b) The saliency of each kind of stimulus was modulated by creating intermediate images containing *x*% of the stimulus and 100 – *x*% of noise, where *x* could be either 5%, 9%, 13%, 17%, 21% or 25%.