



The amodal system for conscious word and picture identification in the absence of a semantic task

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ABSTRACT

Previous studies using explicit semantic tasks, such as category or similarity judgments, have revealed considerable neuroanatomical overlap between processing of the meaning of words and pictures. This result may have been influenced by the semantic executive control required by such tasks. We examined the degree of overlap while minimizing semantic executive demands. In a first fMRI experiment ($n = 28$), we titrated word (35.3 ms, $SD = 9.6$) and picture presentation duration (50.7 ms, $SD = 15.8$) such that conscious stimulus identification became a stochastic process, with a 50% chance of success. Subjects had to indicate by key press whether or not they had been able to identify the stimulus. In a second fMRI experiment ($n = 19$), the identification runs were followed by a surprise forced-choice recognition task and events were sorted on the basis of subsequent memory retrieval success rather than a subjective consciousness report. For both words and pictures, when stimulus processing exceeded the conscious identification threshold, the left occipitotemporal sulcus (OTS), intraparietal sulcus, inferior frontal junction, and middle third of the inferior frontal sulcus (IFS) were more active than when subjects had been unable to identify the stimulus. For both words and pictures, activity in two of these regions, IFS and OTS, predicted subsequent memory retrieval success. A Bayesian comparison revealed that the effective connectivity between IFS and the word- or picture-specific systems was mainly mediated via its connections with OTS. The amodal nature of left OTS and IFS involvement in word and picture processing extends to tasks with minimal semantic executive demands.

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Introduction

The substrate for shared versus input modality-specific processing of meaning of words versus pictures has received a great deal of attention, both in patient lesion studies (Rapp et al., 1993; Chertkow et al., 1997; Rogers and McClelland, 2004) and in functional imaging of the intact brain (Vandenberghe et al., 1996; Wagner et al., 1997; Buckner et al., 2000; Thierry and Price, 2006; Vandenberghe et al., 2006, 2007). Candidate regions involved in amodal processing, i.e., processing of meaning of concrete words as well as pictures, are the ventral occipitotemporal cortex (Buckner et al., 2000), the posterior third of the left middle temporal gyrus (Chertkow et al., 1997; Vandenberghe et al., 2007; Kircher et al., 2009), the anterior temporal pole (Hodges et al., 1992; Vandenberghe et al., 1996; Rogers and McClelland, 2004), the left inferior frontal sulcus (Wagner et al., 1997), the anterior inferior frontal gyrus (Goldberg et al., 2007), and the left middle frontal gyrus (Demb et al., 1995; Vandenberghe et al., 1996).

Many tasks that have been used to study commonality between cognitive processing of words and pictures have required at least some degree of explicit task-related retrieval of the associations and meaning of the referent. This is true for relatively demanding tasks with a high decision weighting component such as the Pyramids and Palm Trees test (Howard and Patterson, 1992; Vandenberghe et al., 1996) but also for relatively easy tasks that require subjects to explicitly retrieve well-known and typical features of the referent such as living–nonliving judgments (Wagner et al., 1997), sound, or colour matching (Garrard and Carroll, 2006), etc. Task-related deployment of strategies for retrieving, comparing, or deciding about semantic properties and associations may partly account for the commonality in activity pattern between words and pictures in these studies, in particular in the prefrontal cortex.

Other neuroimaging studies of amodal processing have made use of automatic semantic priming (Rissman et al., 2003; Sachs et al., 2008; Kircher et al., 2009; Sass et al., 2009) and combined words and pictures cross-modally (Kircher et al., 2009; Sass et al., 2009). During speeded lexical decision, the left posterior middle and superior temporal cortex shows a semantic relatedness effect during automatic priming (Copland et al., 2003; Gold et al., 2006) for word–word pairs

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and for picture–word pairs (Sachs et al., 2008; Kircher et al., 2009; Sass et al., 2009). Subliminal (masked) priming removes the strategic semantic effects altogether (Forster, 1998; Holcomb and Grainger, 2006; Diaz and McCarthy, 2007; Grainger and Holcomb, 2009). Neuroimaging studies of subliminal (masked) priming have reported differential effects in left fusiform cortex for word–word pairs comparing same versus different words (Dehaene et al., 2001; Qiao et al., 2010) and in the left posterior fusiform cortex for picture–picture pairs comparing repeated versus unrepeated pictures (Eddy et al., 2007). Cross-modal effects or within-study overlap between word–word and picture–picture priming effects have not been reported in neuroimaging studies of subliminal priming until now to the best of our knowledge. Prefrontal supraliminal priming effects (suppression or enhancement) have been reported at various locations distributed over the lateral convexity (Wagner et al., 1997; Copland et al., 2003; Rissman et al., 2003; Raposo et al., 2006; Race et al., 2009). This variability may relate to differences in the balance between automatic versus strategic component processes (Copland et al., 2003; Gold et al., 2006), but it could also be a consequence of the relatively small effect sizes and the inherent inability of fMRI to capture the time dependency of priming effects.

For the first time, we applied a method to the study of amodal processing that stems from the consciousness research field (Kanwisher, 2001; Bar et al., 2001; Marois et al., 2004; Carmel et al., 2006; Wilenius-Emet et al., 2004). At brief stimulus durations, conscious stimulus identification is a probabilistic process. For each individual and each input modality, we selected a duration of word or picture presentation so that subjects reported conscious identification of the stimulus only with a probability of 50% across items (Marois et al., 2004; Carmel et al., 2006; Wilenius-Emet et al., 2004) and also within items across subjects. In this way, sensory input was matched between events that were associated with conscious processing and events in which processing remained subliminal. We tried to detect zones of amodal cognitive processing during supra- versus subliminal word and picture identification. In a previous study of speeded picture identification (Bar et al., 2001; Bar et al., 2006), activity in mid and anterior fusiform cortex correlated with the subjects' level of confidence that they had been able to identify the pictures correctly, ranging from zero (no stimulus perceived) to five (fully confident about stimulus identity), with also orbitofrontal involvement (Bar et al., 2006). In that study, confidence was manipulated by repeating the same stimuli up to 6 times. Only pictures were used (Bar et al., 2001; Bar et al., 2006). Our cross-modal design allowed us to examine whether these fusiform and other regions are shared between words and pictures during supra- versus sub-threshold processing while sensory characteristics and prior exposure were strictly matched between supra- and subliminally processed stimuli.

How does conscious processing of a word or picture differ from subliminal processing? According to the Theory of Visual Attention (TVA) (Bundesen, 1990; Bundesen et al., 2005; Bundesen and Habekost, 2008), conscious processing takes place when a perceptual entity is selected among other competing entities and gains access to visual short-term memory (VSTM) according to a winner-takes-all principle. From VSTM, the consciously perceived unit is made available (“broadcasted”) to other cognitive brain systems, such as declarative memory (Baars, 1988; 2002) or phonological retrieval (Jackendoff, 2007) systems. When we consciously identify a stimulus, the surface features of that stimulus and its visual form become available for subsequent explicit retrieval, as well as the identity of the referent. The central question in this study is whether similar brain networks are involved for word and picture input when stimuli gain access to consciousness. Conscious stimulus identification may in its turn trigger explicit lexical- or associative-semantic processes but the short stimulus durations and the task instruction in our study directed attentional resources towards perceptual identification and away from downstream processes of explicit semantic elaboration.

We determined which regions became activated when perceptual processing exceeded the threshold of conscious identification on the basis of a subjective consciousness report (Frith et al., 1999; Beck et al., 2001; Bar et al., 2001; Haynes et al., 2005). We dealt with the inherent subjectivity of this measure (Frith et al., 1999) in two ways: first, we also included foil stimuli consisting of nonexistent chimeras. Subjects were instructed to respond negatively to the foil stimuli, i.e., in the same way as to stimuli that they had not been able to identify. When the false-positive response rate to foil stimuli was too high, we excluded the run. In case of pictures this task is very similar to the object decision test (Riddoch and Humphreys, 1993), a classical neuropsychological task that probes the structural description level of processing. According to the Hierarchical Interactive Theory (HIT) (Humphreys and Forde, 2001), the activation of a structural description of the object is necessary for object identification and distinct from the associative-semantic level (Humphreys and Forde, 2001). At the structural description level, visual percepts are matched with mnemonic presentations of real-life entities in a way that is invariant for viewpoint, size, orientation, etc., and generalizes across different exemplars of a same entity (Humphreys and Forde, 2001).

As a second measure to circumvent the subjectivity of a consciousness report, we only retained regions that also fulfilled a second, more objective criterion: following runs of subjective consciousness report, we conducted a surprise forced-choice yes/no recognition task and sorted events on the basis of subsequent memory retrieval success rather than subjective consciousness report. Only regions that stringently fulfilled both criteria, an association with a positive consciousness report and with successful encoding, conjointly for words and for pictures, were retained as amodal zones of supra-versus subliminal processing. To further verify the level and accuracy of stimulus identification and also to evaluate how the extent of the amodal activations obtained in the first and second experiment related to those obtained in more classical tasks, we conducted a third, overt naming/reading fMRI experiment.

Materials and methods

Subjects

Twenty-eight healthy native Dutch speakers (15 women and 13 men, between 19 and 29 years of age) participated in the first fMRI experiment, which was based on the subjective consciousness report, and 8 additional subjects (3 women and 5 men, age range 19–25 years) in a control experiment. Nineteen other subjects (12 women and 7 men, between 19 and 35 years of age) participated in a third fMRI experiment, the subsequent memory retrieval experiment. Four other subjects (1 man and 3 women, between 21 and 23 years of age) participated in a fourth, overt naming/reading fMRI experiment. All participants were strictly right-handed (Oldfield, 1971), free of psychotropic and vasoactive medication, and without neurological or psychiatric history. They all gave written informed consent in accordance with the Declaration of Helsinki. The experiments were approved by the Ethics Committee, University Hospitals Leuven.

Stimuli and tasks

First experiment

Visual stimuli were presented foveally and projected from a Barco 6400i LCD projector (1024 × 768 pixels) at a refresh rate of 75 Hz onto a screen 36 cm in front of the subject's eyes. Subjects viewed the screen using a mirror attached to the head coil.

Each trial consisted of a forward mask (duration 200 ms), a written word (duration x_{word} ms) or a picture (duration x_{picture} ms) and a backward mask (1700 ms – x_{word} or x_{picture} , respectively), followed by a fixation point (duration 350 ms) (Fig. 1A). Subjects had to indicate by key press whether or not they had been able to identify the

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