Grammatical classes in the brain: MVPA reveals the cortical signature of verbs, adjectives and nouns

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Introduction:

The processing of open word classes has been largely investigated in brain sciences. However, crucial questions remain open. While much attention has been given to the Noun/Verb distinction, how adjectives are represented in the brain is almost entirely unknown [7]. Moreover, findings on the neuroanatomical correlates of nouns and verbs still remain widely controversial. The most consistent result across brain imaging studies is a verb selectivity in the left Lateral Temporal Cortex, which only partially, though, matches the results of lesion studies [9,10]. Also, the role of critical verb features in driving verb-selective regions remains unsettled [5]. In this study, we investigated the cortical signature of verbs, nouns and adjectives as grammatical categories.

Methods:

We used fMRI (GE 3T) to examine neural activity in 15 [5F; age: 29 ± 4 years, years of education: 18 ± 2] right-handed native Italian healthy volunteers while they performed a match-to-sample task. Stimuli were Italian verbs (e.g., cadere "to fall", costruire "to build"), nouns (e.g., nesso "link", tavolo "table") and adjectives (e.g., simile "similar", sottile "thin"), matched for form and lemma frequency, length in letters and number of core arguments of verbs. They were also balanced for relationality, the only interface semantic feature inherent in all verbs, and rated for familiarity, imageability and concreteness by an independent group of 94 subjects. Three stimuli and a probe, always from the same word class, were visually presented for 1.5s each, with a 6s inter-trial interval. Subjects were asked to respond whether or not the probe stimulus was semantically related to one of the three preceding stimuli. After standard preprocessing with AFNI [2], the scores of the three independently controlled features were regressed out for each stimulus. Residual BOLD response in language-sensitive regions [3] was then used in a multi-class searchlight-based classifier, whose accuracies were tested as significantly different from chance by a permutation test [6,8].

Results:

Familiarity, imageability and concreteness significantly correlated with neural response within a well-known language network ($R2=0.10$; $p<0.05$, corrected for multiple comparisons). Searchlight analysis performed on word classes ($p<0.05$, corrected for multiple comparisons) revealed distinct brain regions in the left hemisphere selectively engaged by verbs (posterior middle temporal gyrus, inferior frontal gyrus), adjectives (antero-lateral-temporal lobe), nouns (antero-medial-temporal lobe). In addition, word class-selective areas were found from anterior to posterior temporo-parieto-occipital junction, in an adjectives-nouns-verbs order.

Conclusions:

This study identified selective functional brain correlates of the distinct grammatical categories of verb, adjective and noun within a left-lateralized language network. These results provide the first robust indication of the neural underpinning of nouns and the first evidence on the representation of adjectives as grammatical category, thus making specific contributions also to the study of

conceptual combination processes associated with the left antero-lateral-temporal lobe [1]. Moreover, these data confirm the most consistent neuroanatomical findings from previous studies on verb-selectivity and provide new evidence on how bare grammatical category information is represented in the brain when stimuli are controlled for crucial semantic features of verbs, as opposed to other word classes, and the effect of familiarity, imageability and concreteness is ruled out [4]. In summary, this study specifically expands the current knowledge on how grammatical categories are captured in the brain, by assessing the role of language-sensitive regions in representing word classes and by identifying the kind of distinctions that drives neural selectivity.

Imaging Methods:

BOLD fMRI [2]

Language:

Language Comprehension and Semantics [1]

Language Other

Keywords:

FUNCTIONAL MRI

Language
Multivariate
Other - Grammatical categories; adjectives

[1|2]Indicates the priority used for review

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Please indicate which methods were used in your research:

Functional MRI

For human MRI, what field strength scanner do you use?

3.0T

Which processing packages did you use for your study?

AFNI

Provide references in author date format

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INTRODUCTION

The processing of open word classes has been largely investigated in brain sciences. However, crucial questions remain open.

•While much attention has been given to the noun/verb distinction, how adjectives are represented in the brain is almost entirely unknown [7].

•Moreover, findings on the neuroanatomical correlates of nouns and verbs still remain widely controversial. The most consistent result across brain imaging studies is a verb selectivity in the left Lateral Temporal Cortex, which only partially, though, matches the results of lesion studies [9,10].

•Also, the role of critical verb features in driving verb-selective regions remains unsettled [5].

In this study we assessed the cortical signature of word classes (nouns, verbs, adjectives) through a multivariate, searchlight-based classifier, by testing whether word class-specific information is represented independently of both relationality (the only necessary semantic property of verbs) and word features such as imageability, concreteness and familiarity.

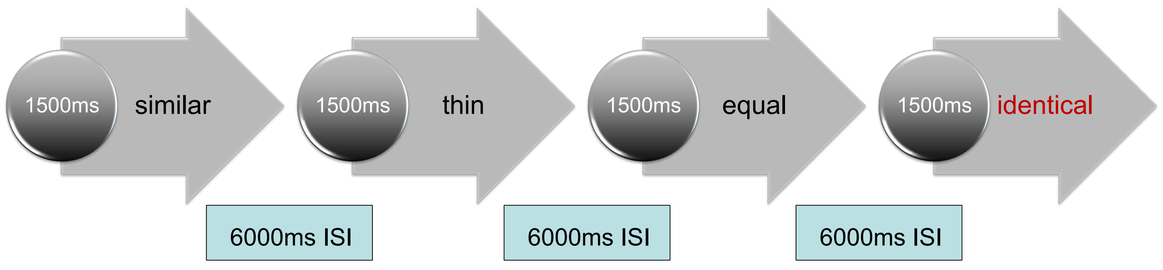


Fig. 1. Experimental Design

METHODS

◆ Participants

Fifteen [5F; age (mean ± SD): 29 ± 4 years; education: 18 ± 2 years] right-handed healthy native Italian volunteers. The study was approved by the local Ethical Committee.

◆ Stimuli

Italian verbs (e.g., *cadere* "to fall", *costruire* "to build"), nouns (e.g., *nesso* "link", *tavolo* "table") and adjectives (e.g., *simile* "similar", *sottile* "thin") matched for form and lemma frequency, length in letters and number of core arguments of verbs, balanced for relationality, and rated for familiarity, imageability and concreteness by an independent group of 94 subjects. [age (mean ± SD): 28 ± 9 years; education: 16± 2 years].

◆ Experimental Paradigm

In an event-related design, three stimuli and a probe from the same word class were visually presented for 1.5s each, with a 6s ITI. Subjects responded by button pressing whether or not the probe stimulus was semantically related to one of the three preceding stimuli (Fig. 1). There were 80 trials, with each stimulus repeated three times, randomly scattered across eight runs and never repeated within trial. A behavioral task assessment study was conducted [20 subjects, 12F; 23 ± 3 years] to rule out that neural responses to different word classes were related to different degrees of task difficulty between classes.

◆ MRI Scanning and Data Analysis

- 3T GE scanner: GRE-EPI images (TR 2.5s, FA: 75°, TE 30ms, FOV = 25.6 cm, in-plane resolution 128 x 128, 42 axial slices, voxel size 2x2x3 mm).
- After standard preprocessing with AFNI [2], the scores of the three independently controlled features were regressed out for each stimulus. Residual BOLD response in language-sensitive regions [3] was then used in a multiclass searchlight-based classifier (accuracies tested as significantly different from chance by a permutation test [6,8]).

RESULTS

Fig. 2. F, I and C effect on BOLD signal

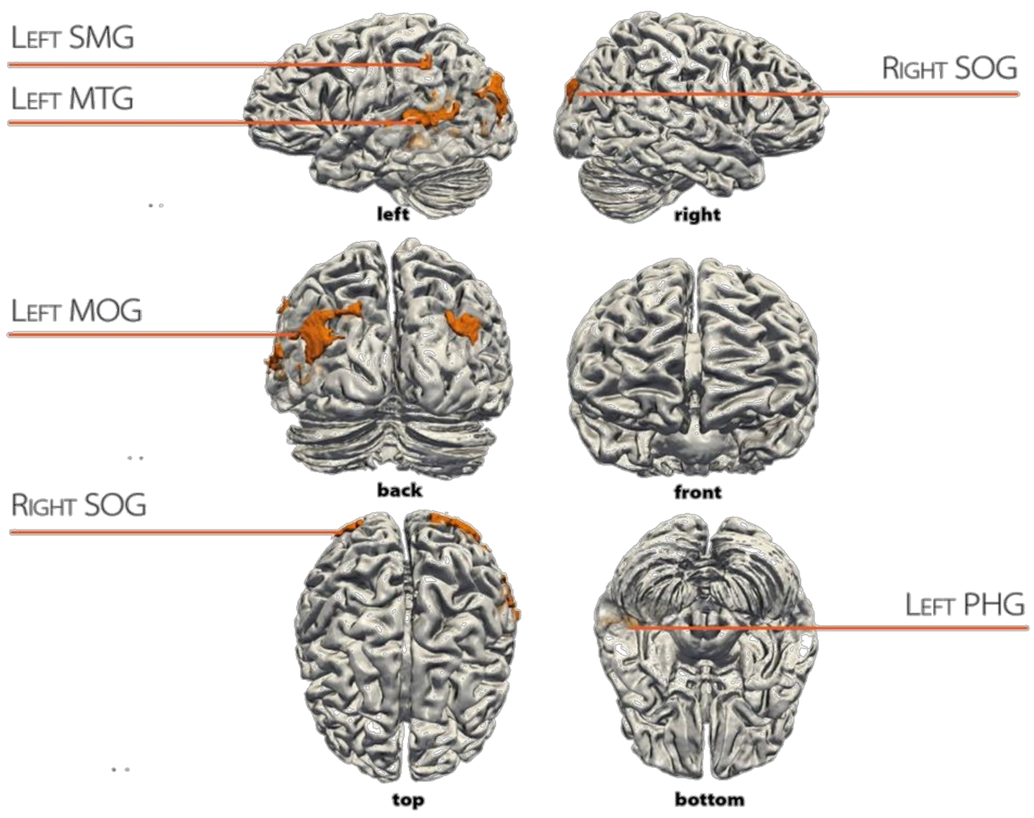
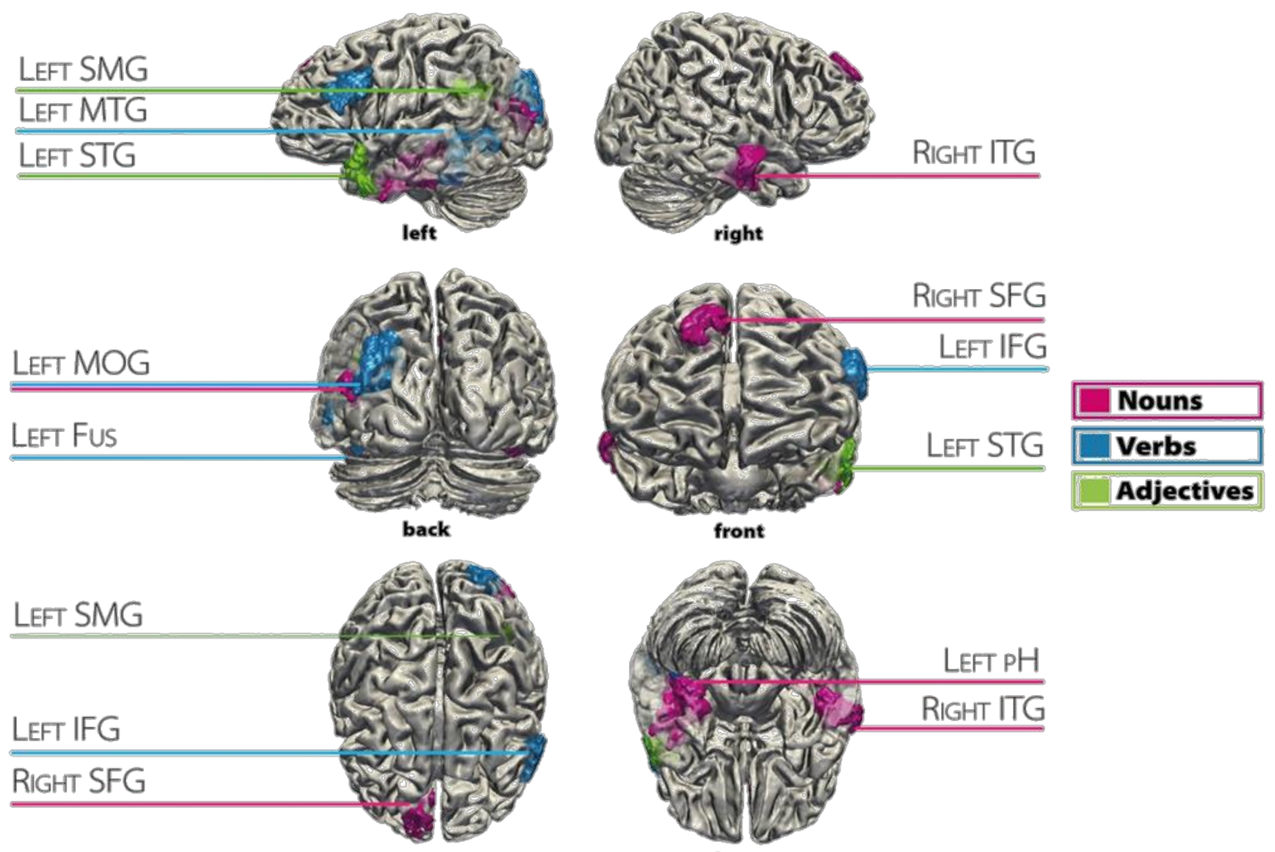


Fig. 3. Regions where searchlight-based MVPA yielded the highest accuracy for each word class



◆ Behavioral Results

In the stimulus and task assessment study, class mean (±SD) performance accuracy was **85.3**% ±0.067 (Adjectives); **88.7**% ±0.070 (Nouns); **84.3**% ±0.075 (Verbs); and mean reaction times by class were **1075.1** ± 356.5 ms (Adjectives); **1083.6** ± 348.3 ms (Nouns); **1038.4** ± 313.4 ms (Verbs). No significant differences were found across conditions.

◆ fMRI Results

Familiarity (F), imageability (I) and concreteness (C) significantly correlated with neural response within a well-known language network (R^2 up to 0.10; corrected $p<0.05$) (Fig. 2).

Searchlight-based classification performed on word classes ($p<0.05$, corrected for multiple comparisons), after regressing out F, I and C, revealed brain regions preferentially engaged nouns, verbs, adjectives (Fig. 3).

CONCLUSIONS

This study identified selective functional brain correlates of the distinct word classes of verb, adjective and noun within a left-lateralized language network.

- These results provide the first robust indication of the neural underpinning of nouns and the first evidence on the representation of adjectives as grammatical category, thus making specific contributions also to the study of conceptual combination processes associated with the left anterolateraltemporal lobe [1].
- Moreover, these data confirm the most consistent neuroanatomical findings from previous studies on verb-selectivity and provide new evidence on how bare grammatical category information is represented in the brain when stimuli are controlled for crucial semantic features of verbs, as opposed to other word classes, and the effect of familiarity, imageability and concreteness is ruled out [4].

In summary, this study specifically expands the current knowledge on how grammatical categories are captured in the brain, by assessing the role of language-sensitive regions in representing word classes and by identifying the kind of distinctions that drives neural selectivity.

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