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NOUNS AND VERBS IN THE BRAIN: NEUROPSYCHOLOGICAL, PSYCHOLINGUISTIC AND NEUROIMAGING EVIDENCE

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“Chi ha qualcosa da dire
si faccia avanti e taccia”

Karl Kraus

Sento la mancanza dei miei nonni.
Di quella generazione dalla pelle dura e il cuore forte,
di quegli uomini e donne che sapevano tenere la schiena dritta,
e parlare ad alta voce.
La generazione che ci ha liberato.

A Giacomo e a tutti i bimbi,
perché crescano nell’amore della verità
e ci ridonino un mondo coraggioso.

SUMMARY

1 INTRODUCTION

When the seminal psychological models of the human linguistic system were put forward in the second half of the nineteenth century (Wernicke, 1874, Lichtheim, 1885, Freud, 1891), word representations were thought to be acoustic patterns and motor engrams: these word images sub-served language comprehension and language production, and were strictly connected to each other in the context of a sensory-motor association. Thanks to the development of cognitive psychology and psycholinguistics (which redefined some philosophical concepts like *representation*) and thanks to the birth of modern theoretical linguistics (which overcame a purely descriptive level and began giving interpretation of linguistic phenomena in terms of theoretical constructs like, e.g., phrase and phoneme), a new definition of *mental lexicon* emerged since the early 1960s and evolved over the last 50 years: in recent cognitive models the mental lexicon is made of representations in the modern sense, i.e., abstract mental entities that can be manipulated through algorithms and store all the relevant information about the characteristics and the behaviour of the words they represent (e.g., grammatical class, argument structure, phonological form; Dell et al., 1997; Levelt et al., 1999; Coltheart et al., 2001). This conceptualization of the mental lexicon triggered cross-fertilization between cognitive psychology and theoretical linguistics; indeed, in the last 20 years the primary goal of psycholinguistics, cognitive neuropsychology and cognitive neuroscience has been to find out whether the constructs proposed by theoretical linguists truly reflects the structure of the mind.

The definition of nouns and verbs: theoretical linguistics

Grammatical classes

One of the most intriguing theoretical constructs proposed by linguists is *grammatical class*. This concept refers to one of the most basic intuitions of native speakers: words behave differently, i.e., they sub-serve different goals in communication and, hence, have different inherent properties and undergo different linguistic phenomena. Although this is a very basic intuition of any native speaker, it is not easy to capture formally, i.e., it is not immediate to single out a set of properties that are necessary and sufficient to characterize all the words belonging to a specific grammatical class. Take nouns and verbs for example. It is shared knowledge that nouns refer to object, whereas verbs refer to actions. However, this criterion is clearly not sufficient to correctly tease apart nouns and verbs: *destruction* indicates an action and would thus be classified as a verb, contrary to the speakers' intuition. The criterion tested above is *inherent*, i.e., based on intrinsic characteristics of a word (e.g., the semantic content): much better work is done by *distributional* properties, i.e., those referring to the position that words can/cannot occupy in sentences. As an example, verbs can directly precede a proper noun within a phrase, as in (a), whereas nouns cannot, but do need a preposition, as shown in (b) and (c):

a. Paul betrayed Mary
b. *The betrayal Mary carried out by Paul
c. The betrayal *of* Mary carried out by Paul

Not only the distribution of words in sentences, but also the distribution of morphemes in words may clearly differentiate classes of words: e.g., the morpheme *-ment* can only be attached to verbs (e.g., *depart*$_V$*-ment, involve*$_V$*-ment, entrap*$_V$*-ment*), and not to nouns (**cat*$_N$*-ment, *joy*$_N$*-ment*).

In conclusion, it is possible to distinguish words in grammatical classes, the differentiation being mostly based on the distributional properties of words in sentences, and of morphemes in words.

Nouns and verbs

Language can be used to fulfil several goals, e.g., affirming a state of the world, asking whether that state of the world holds, enacting a state of the world (as in *performative* verbs, e.g., "I declare you, in the name of God, husband and wife"). All these linguistic acts have something in common: the communication focuses on a state of the world, on the fact that *something is something*. In other words, any linguistic communicative act (with very few and controversial exceptions, like weather verbs, e.g., *piovere*, to rain) has a core in which, on the one hand, a specific object of the world is singled out (*denotation*) and, on the other hand, some properties are attributed to this object (*predication*; see for example Chomsky, 1995).

This basic distinction in language (or, more properly, in communication) between *denotation* and *predication* may be conceived as lexically reflected in the differentiation between nouns and verbs: the elements in the former category would naturally sub-serve denotation, while the words belonging to the latter class would naturally predicate properties and relationships about what is denoted by nouns. Nouns and verbs would thus have a privileged status among grammatical classes. Indeed, there is some fact supporting this hypothesis: a basic differentiation between nouns and verbs has been found virtually in all known languages, with very few and controversial exceptions (e.g., Robins, 1952, Langacker, 1987, Foley, 1998). The predominance of nouns and verbs over the other grammatical classes is also attested in some theoretical accounts; as an example, the four grammatical classes playing the role of head in lexical phrases (nouns, verbs, adjectives and prepositions) have been formally described on the basis of two binary features, [noun] and [verb], nouns being [noun +][verb -], verbs [noun -][verb +], adjectives [noun +][verb +] and prepositions [noun -][verb -] (see Chomsky, 1970).

A reflection of the denotation-predication continuum is rather widespread in the linguistic definition of what nouns and verbs are. A fundamental characteristic of *verbs* is that they are argument taking. They represent eventualities typically in the form of relations among the protagonist of such eventualities (see Dowty, 1989). For example, *give* characterizes an event *e* which involves a three place relation between an agent (x_{AG}, the giver), a theme (x_{TH}, what is given) and a goal (x_{GO}, the end point of the transaction). Hence, it is a widely accepted fact in theoretical linguistics that verbs have a list of their obligatory arguments (often called *adicity*) taking this form:

d. /walk/ WALK($\mathbf{x}_{AG}$)

e. /drink/ DRINK($\mathbf{x}_{AG}$, y_{TH})

f. /give/ GIVE($\mathbf{x}_{AG}$, y_{TH}, z_{GO})

The arguments represent the participants in the event. They have a label (e.g., agent, theme, goal) indicating their thematic role. The external argument (intuitively, the one corresponding to the subject) is marked in boldface. Obligatory arguments (whether internal or external) must be syntactically projected, i.e., there must be corresponding nodes in the syntactic tree suitably filled with lexical material that provides the argument slot of the verb with semantic content. As it clearly emerges from this brief description of the verb representation as it is conceived in theoretical linguistics, the arguments structure has a great relevance in defining what a verb is: so to say, verbs *are* their argument structure.

Consider, by contrast, the case of *nouns*. Many nouns simply do not have argument structure in the relevant sense: they are not argument taking. In particular, this is the case for all *sortals*, i.e., nouns that refer to a set of concrete objects sharing some properties (e.g., *chair* refers to all those inanimate objects typically having four legs and a back, on which a single person can sit). There are of course nouns that are, in some sense, argument taking; as an example, some nouns, like, e.g., *neighbour, enemy, mother*, are inherently relational. A further important type is that of *deverbal nouns*, and, more generally, nouns that are morphologically related to verbs (such as *arrive/arrival, destroy/destruction, attack/attack*); nouns of this kind inherit the thematic structure of the related verbs. However, even if some preservation of the thematic structure is clearly present, it is also clear that the way deverbal nouns take arguments is very different from the way verbs do. This is certainly true for Italian and English; but possibly holds universally. The crucial fact here is that deverbal nouns, in contrast with verbs, *never take their arguments obligatorily*, as it clearly emerges from the following contrasts:

a. *donated	a'. the donation
b. *Paul donated	b'. Paul's donation
c. *Paul donated to the library	c'. Paul's donation to the library
d. Paul donated a rare book to the library	d'. Paul's donation of a rare book to the library

Whatever semantic/syntactic explanation of these contrasts one may adopt, it is a fact that the argument structure of *donate*, although inherited by the corresponding noun *donation*, is somehow de-emphasized. Nouns can be used without their arguments, while verbs typically do not. More specifically, the capacity to project arguments does not seem to be a prerequisite to the use of nouns in the way it is to the use of verbs.

Another aspect in which the characteristics of nouns and verbs seem to reflect the denotation/predication dichotomy is the syntactic case. Consider the following sentences:

a. Paul kissed Mary	a'. *Paul waited Mary
b. *Paul kissed for Mary	b'. Paul waited for Mary

The insertion of the preposition *for* between the main verb and the following noun has opposite effects in (a) and (b) as compared to (a') and (b'); while in the first pair it makes the sentence ungrammatical, in the second pair it is necessary in order for the sentence to be correct. As (a) and (a'), and (b) and (b') are completely identical as far as their syntactic structure is concerned, the difference can only lie in the main verbs, *to kiss* and *to wait*. They both take two arguments, an agent and a theme; however, the former is transitive and the latter intransitive, the difference lying in the fact that *to kiss* assigns a grammatical case to its internal argument (i.e., the object), while *to wait* does not. The grammatical case can be phonologically and morphologically silent (as in Italian, for instance), but nonetheless must be assigned to any noun in order for the sentence to be correct (this constraint is called *case filter*; see Chomsky, 1981). Now an explanation is available for the non-grammaticality of (a') and (b). In (a) the main verb *to kiss* gives a grammatical case to *Mary*, thus satisfying the case filter. This does not happen in (a'), where *to wait*, being intransitive, does not give a case to its object *Maria*: the case filter is not satisfied and thus the sentence is ungrammatical. Consider that also prepositions give a grammatical case to nouns (Chomsky, 1970): this explains why (a') is not grammatical (the preposition would give a second case to *Mary* and this is not allowed by the case filter) and, by contrast, (b') is finally acceptable (*Mary* receives from the preposition the case that is not assigned by the main verb). Therefore, the grammaticality of the sentences in (a), (b), (a') and (b') is based on a neat distinction between nouns and verbs for what concerns their role in grammatical case handling: while nouns cannot be expressed phonologically unless marked by case, verbs do assign case.

From linguistics to cognitive psychology

As we have shown above, the main point offered by theoretical linguistics to cognitive neuroscience is that through a variety of devices (ranging from morphology to position in clause) native speakers seem to distinguish verb roles from noun roles. The former (i.e., verbs) are typically heads of predicative complexes. The latter (i.e., nouns) typically play the role of arguments in predicative structures. We are going, therefore, to assume that there is a level of grammatical representation (in the lexicon or, possibly, in the syntax) where nouns and verbs are structurally (categorically) distinguished. The primary concern of the studies included in this thesis is whether such distinction, which we take to be well motivated on linguistic grounds, is also founded in a psycholinguistic frame, i.e., is represented in the human mind.

This issue will be addressed under two different points of view. First, we will try to clarify the functional differentiation between nouns and verbs in the human mental lexicon. This will be firstly done by studying aphasic patients suffering from disproportionate impairment in retrieving either nouns or verbs: in particular, the spontaneous speech of these patients will be compared with their naming ability in a picture naming task in order to clarify the nature of the cognitive damage underlying the noun-verb dissociation. Furthermore, the functional differentiation between nouns and verbs will be addressed through the investigation of the relationship between part-of-speech and priming effects: the grammatical class of primes and probes will be manipulated – thus studying both within-class and cross-class priming effects – in order to see how part-of-speech influences the facilitation between semantically and/or morphologically related words. The instantiation of the noun-verb dichotomy in the human linguistic system will be also addressed by assessing whether different brain areas are involved in the lexical access/retrieval of the two grammatical classes: an fMRI study will be carried out with a factorial design allowing us to single out noun-verb effects that replicate reliably across different tasks, thus indicating an (at least partial) segregation of the neural circuits sub-serving noun and verb lexical retrieval.

The functional differentiation of nouns and verbs: neuropsychological accounts of the noun-verb dissociation

The special status shown by these two grammatical classes has attracted the attention of psychologists and cognitive scientists who have been investigating the noun/verb dichotomy under different points of view over the last 30 years. The interest on how nouns and verbs are represented in the human mind firstly arose in neuropsychology, with the observation of a dysgraphic patient whose spelling was significantly better on nouns than verbs (Baxter and Warrington, 1985) and of an agrammatic aphasic patient whose production and comprehension of verbs was more impaired as compared to those of nouns (McCarty and Warrington, 1985). These seminal papers (see also Holmes et al., 1971 and Miceli et al., 1984) were followed by many others in which brain-damaged patients suffering from predominant impairments of nouns or verbs were reported in writing (Rapp and Caramazza, 2002), oral picture naming (Zingeser and Berndt, 1988), written picture naming (Caramazza and Hillis, 1991), written comprehension (Hillis and Caramazza, 1995) and spontaneous speech (Bastiaanse and Jonkers, 1998). This wide range of cases resulted in several theoretical accounts of the noun-verb dissociation, each of which has relevant implication for the representation of grammatical class in the linguistic system.

According to Caramazza and colleagues (e.g., Caramazza and Hillis, 1995, Rapp and Caramazza, 2002), dissociated impairments may be caused by damage*,* which selectively affects verbs or nouns at a late lexical stage (phonological or orthographic output lexica). This conclusion is drawn from the fact that a noun-verb dissociation may appear in some linguistic tasks, but not in others: for instance, patient SJD suffered from verb impairment only in written naming and spelling to dictation, but not in oral naming and in reading; on the contrary, patient HW suffered from verb impairment in a spoken naming task, but not in the written version of the same task (Caramazza & Hillis, 1991). An even more striking pattern emerged in patient EBA (Hillis & Caramazza, 1995): this patient performed better on verbs than nouns in spoken production, and on nouns than verbs in written comprehension. The dissociation between written and spoken output and between production and comprehension has been accounted for by hypothesizing multiple representations of grammatical classes (i.e. noun vs verb) in all four lexica (orthographic and phonological input and output lexica).

Shapiro and colleagues (Shapiro et al., 2000; Shapiro et al., 2001; Shapiro & Caramazza, 2003) have suggested that selective damage of word forms is not the only cause of noun-verb dissociation. They observed some patients who were selectively impaired either in producing the third person of a verb (and of non-words used as verbs, e.g., *I filc - he filcs*) or the plural form of a noun (and of non-words used as nouns, e.g., *one filc - several filcs*). They concluded that these patients had a selective "deficit in retrieving or manipulating syntactic features" of nouns or verbs (Shapiro et al., 2000). However, while these findings are *per se* very interesting, they do not directly account for noun-verb dissociation. The selective impairment of *number features* (which are generally held to be significant on nouns) versus *person features* (significant on verbs), or possibly of the corresponding rule ("inflect for number" versus "inflect for person") might in principle leave the corresponding lexical categories unaffected. In other words, it is conceivable that a deficit might affect either noun or verb inflection without affecting the categories *noun* or *verb* per se. It is also unclear how the deficit identified by Shapiro et al. could explain the difficulty encountered on the picture naming task, in which the relevant morphemes are clearly not called upon.

The existence of a unitary and central lexical-syntactic representation of grammatical class has been claimed by Berndt and coworkers (Berndt et al., 1997a; 1997b; Berndt et al., 2002). They tested ten aphasic patients using several tasks involving isolated words or sentences and deduced that the deficit causing noun-verb dissociation would concern a lexical device, either at an orthographic-phonological modality-specific level (as suggested by

Caramazza and colleagues) or at a unitary lexical-syntactic device (i.e., analogous to the *lemma level* in Levelt et al.'s model, 1999). This claim is based on three major outcomes of the study. A qualitative error analysis shed light on a great number of semantic errors in some patients and on the absence of such errors in others; some patients showed an important word frequency effect, while the imageability effect was significant in others; some patients had considerable deficits both in the production of well-structured sentences and in the comprehension of reversible sentences (two deficits typically related to *lemma* damage), while other patients did not. Altogether, these results seem to indicate two different breakdown loci, with some patients having a *lemma* deficit, and others a *lexeme* deficit.

Bird and colleagues (Bird et al., 2000; Bird et al., 2001; Bird et al., 2002) on the other hand argued that noun-verb dissociation might be a semantic, rather than lexical phenomenon. Moreover, they suggested that many dissociations might be generated by an increased level of sensibility in aphasic patients to a number of semantic differences and imageability in particular. In fact, since nouns refer to concrete objects, they usually have a higher imageability rate than verbs and tests used to assess noun-verb dissociation were frequently not matched for this variable. Furthermore, many studies showed imageability to be an important predictor of patients' ability to retrieve words (e.g. Bates et al., 2001; Luzzatti et al., 2002; Berndt et al., 2002). In spite of Bird et al.'s interesting attempt, strong evidence has emerged in recent studies indicating that, even when arguably a causal relation exists between noun-verb dissociation and imageability, this latter cannot be considered as the only cause of grammatical class effects (Berndt et al., 2002; Luzzatti et al., 2002; Rapp and Caramazza, 2002); however, these findings, do not yet appear to be conclusive (Berndt et al., 2002).

Furthermore, predominant noun impairment is also attested (Berndt et al., 1997; Luzzatti et al., 2002a, 2002b). This phenomenon cannot be explained in terms of imageability, since verbs are systematically less imaginable than nouns. At the same time, the idea that verb impairment may be caused (*in toto* or in part) by an increased imageability effect remains plausible.

According to Bird and co-workers, even patients who continue to manifest dissociation after balancing for imageability are not suffering from a lexical deficit. Their naming impairment would be the result of selective damage to either their sensory or functional semantic features. Since verbs mainly denote actions and action concepts are mainly defined by functional properties, selective damage to functional knowledge may result in verb impairment. Analogously, selective damage to sensory knowledge will result in verb superiority, given that nouns frequently denote concrete objects and that concrete objects are defined above all by their visual-sensory properties. This interpretation, appealing though it may seem, has some drawbacks. The assumption that object concepts are mostly defined by sensory features and action concepts by functional features is rather vague: it lacks a precise definition of the terms "*sensory*" and "*functional*" as well as a clear-cut experimental basis (Farah & McClelland, 1991; Caramazza & Shelton, 1998). Moreover, Bird's explanation predicts that verb impairment should co-occur with better performance on natural objects rather than on artificial objects and, symmetrically, noun impairment should co-occur with better performance on artificial objects rather than on natural objects. However, this prediction is not fully verified empirically.

Finally, noun-verb dissociation has been explained as a consequence of syntactic damage (Saffran et al., 1980; Friedmann, 2000). An early account considered selective verb deficits to be a more general aspect of the agrammatic morphosyntactic impairment (Saffran et al., 1980), while a more recent account specifies the syntactic hypothesis in greater detail (Friedmann, 2000). Verb deficits would result from a pathological pruning of the syntactic tree: therefore, verbs cannot move to the relevant functional categories and be inflected. Syntactic explanations share two major drawbacks: they do not account for verb-superiority nor do they supply a reason why non-agrammatic patients may suffer from selective verb damage.

It is worth to note that, with the only exception of Bird et al.' explanation, all accounts of the noun-verb dissociation refers to an explicit representation of the noun-verb dichotomy in the linguistic system, i.e., lexical entries must be distinguished according to their grammatical class in the lexicon. However, the debate is still open about the level at which lexical nodes are marked for grammatical class. According to Caramazza and colleagues (Hillis and Caramazza, 1991; Caramazza and Hillis, 1995: Rapp and Caramazza, 2002) the information on the noun-verb status is peripheral, i.e., attached to the orthographic and phonological, input and output lexica; by contrast, according to Berndt and colleagues (1997a,b, 2002) and to Crepaldi et al. (2006), the grammatical class information is represented at a more central, lexical-syntactic stage (i.e., the *lemma*).

The wide variety of patients described in the literature seems to indicate that the same surface phenomenon might emerge because of different types of functional damage: indeed, patients showing the same behaviour (e.g., verb-specific difficulty) may actually suffer from different kinds of impairments (e.g., syntactic or semantic or lexical-syntactic or lexical-phonological breakdown). A tool that has been rather systematically neglected and may be useful in disambiguating the different functional damages that may underlie noun-verb dissociation is the analysis of patients' spontaneous speech; Chapter 2 will report on a study in which narrative samples of aphasic patients have been analyzed in order to assess whether grammatical-class-specific impairments also emerge in conversation, arguably under different forms according to the different underlying functional damage.

The functional differentiation of nouns and verbs: psycholinguistics and grammatical class

A representation of the noun-verb dichotomy in a central lexical-syntactic store (the *lemma*) has been put forward also in the psycholinguistic literature by Levelt and colleagues in their influential model of speech production (Levelt, 1989, Levelt et al., 1999). Psycholinguistic evidence for the *lemma/lexeme* dichotomy arises from data on noun grammatical gender (Schriefers, 1993; Vigliocco et al., 1997; van Turennout et al., 1997). Levelt et al.'s model does not implement any further representation of grammatical class: word form nodes are not distinguished according to their grammatical class, since the lexeme level is conceptualized as a purely lexical-phonological stage. Therefore, this model would thus be incompatible with the interpretation of the noun-verb dissociation offered by Caramazza and colleagues, which hypothesizes separate representation for nouns and verbs in the peripheral orthographic and phonological lexica (the *lexeme level* in Levelt et al.'s model).

Besides Levelt et al.'s model, there has been little effort among the psycholinguistic community to clarify the nature of the noun-verb distinction in the human linguistic system. In an ERP study conducted by Pulvermuller et al. (1999) using a lexical decision task, no response time difference emerged between nouns and verbs. Opposite results are reported by Sereno (1999). In this study, RTs (RT) for nouns were faster than for verbs in both a lexical decision task and a noun/verb categorization task: in the latter condition, the author reports a significant interaction between grammatical class and frequency, with high-frequency nouns eliciting faster RTs than high-frequency verbs, but low-frequency nouns being completely comparable to low-frequency verbs. The opposite results obtained by Pulvermuller et al. (1999) and Sereno (1999) may depend on the different procedures used in the two studies. In fact, Sereno focused particularly on hemispheric differences: therefore, stimuli were flashed in one visual hemifield only. Also Chiarello et al. (2002) investigated the interaction between grammatical class and hemisphere in both a lexical decision and word naming task, using nouns and verbs matched for imageability; these authors reported a main effect of grammatical class (with nouns eliciting faster responses than verbs) in Experiment 2, but not in Experiment 1, the only difference between the two Experiments being the order of the block presentation. Altogether, there seems to be no clear evidence on whether nouns and verbs determine different RTs in lexical decision and reading tasks.

None of the studies cited above primarily focused on the functional representation of nouns and verbs, nor any of them directly tried to understand how grammatical class information is represented in the lexicon; the authors were just incidentally addressing this issue while focusing on other aspects of the problem, mostly whether nouns and verbs are processed through distinct neural circuits in different cortical areas. It is highly informative, for example, that the representation of grammatical class has never been addressed though the most stable and widely used psycholinguistic paradigm, i.e., the priming paradigm. Indeed, although this line of research looks highly promising as a tool to investigate whether nouns and verbs are differently represented in our linguistic system (and, if so, how and where), the interaction between grammatical class and priming effects has never been directly considered. We will address this issue in Chapter 3 by means of three priming experiments in which grammatical class of primes and probes has been manipulated.

The cerebral differentiation of nouns and verbs: grammatical-class-specific activations in the brain

As the functional difference between the two grammatical classes received further substantiation, an increasing number of studies addressed the issue of whether different neural circuits underlie noun and verb processing. In recent years many studies have tried to identify the brain areas underlying nouns and verbs processing, either using neuroimaging techniques (PET: e.g., Warburton et al., 1996; fMRI: e.g., Tyler et al., 2004; MEG: e.g., Sörös et al., 2003), Transcranic Magnetic Stimulation (TMS; e.g., Cappa et al., 2002) or anatomo-physiological correlations (e.g., Aggujaro et al., 2006). The results of this effort are very far from constituting a clear picture though, as they do not converge on a well-established pattern of cerebral areas.

This barely consistent picture is possibly due to the fact that different experimental and baseline tasks have been used in different studies (e.g., Fujimaki et al., 1999; Grossman et al., 2002; Shapiro et al., 2005; Saccuman et al., 2006), often without taking in the proper consideration the different cognitive levels they tap on. Indeed, the lexical representation of nouns and verbs has been investigated through lexical decision, picture naming, semantic decision or fluency tasks, and each of these tasks has been compared to different baselines: however, these tasks call into play different cognitive processes (e.g., lexical access, semantic elaboration, phonological encoding), each of which is most likely carried out by different neural circuits. Even more importantly, each of these cognitive processes may, or may not, *per se* distinguish between nouns and verbs.

Moreover, previous neuroimaging experiments showed little control over lexical-semantic variables (e.g., frequency, imageability, stimulus complexity) that have been found to have a role in predicting both the performance of aphasic patients (e.g., Nickels and Howard, 1995) and the RTs of normal speakers on naming tasks (e.g., Bates et al., 2002). As an example, only two studies have considered imageability when addressing the brain areas underlying noun and verb processing. In a study investigating both lexical decision and semantic categorization, Tyler and colleagues (2001) did not report any brain area that was sensitive to either grammatical class or imageability. The authors explain these results by suggesting that grammatical class effects arise only in tasks requiring the use of grammatical class information for the purposes of morphological processing; in other words, part-of-speech effects should be expected only in tasks where stimuli must be inflected. In the other study in which imageability was controlled (Bedny and Thompson-Schill, 2006), the authors compared a semantic decision task on written stimuli to passive viewing of a crosshair. They found a significant interaction between grammatical class and imageability in the left inferior frontal gyrus (LIFG) and in the left middle temporal gyrus (LMTG): when stimuli were highly imageable, these areas responded more to verbs than nouns, whereas, when stimuli were poorly imageable, the BOLD signal was higher for nouns than for verbs. The authors argued that this interaction could be explained by the number of meanings underlying a word. In fact, Bedny and Thompson-Schill suggest that, while verbs tend to be polysemic as they are higher in imageability, the opposite trend holds for nouns, i.e., they tend to be polysemic as they are lower in imageability. In keeping with this assumption, the LIFG and the LMTG would be systematically associated with the stimuli having more alternative meanings (high-imageability verbs and low-imageability nouns). This result – and its interpretation – would thus suggest that the LIFG and the LMTG might not be specific for grammatical class, but could come into play in the case of competition between alternatives during lexical access, resulting in a higher processing load.

The issue on the cerebral areas underlying noun and verb processing is not clarified by taking into consideration evidence obtained through other methodologies. Anatomo-correlative studies on aphasic patients suggest that selective impairment for naming objects is associated with lesions centred on the temporal lobe (Damasio and Tranel, 1993; Glosser and Donofrio, 2001; Hillis et al., 2002). On the contrary, large lesions usually involving the left frontal cortex often underlie selective impairment in naming verbs (see Daniele et al., 1994 and Shapiro and Caramazza, 2003 for a review). Nonetheless, several studies report patients with verb impairment whose lesions lie outside the left frontal regions (Daniele et al., 1994; Silveri and Di Betta, 1997; Silveri et al., 2003), while patients have been reported without verb impairment but with left prefrontal lesions (De Renzi and Di

Pellegrino, 1995). More recently, Aggujaro et al. (2006) reported that in the majority of patients with disproportionate impairment of nouns, the lesion involved the medial part of the middle and inferior left temporal gyri. By contrast, patients with disproportionate impairment of verbs clustered in two major subsets according to the type of aphasia they suffered from: in most fluent patients the lesion involved the left posterior temporal lobe and the left inferior parietal lobe, whereas agrammatic patients suffered from an extensive left fronto-temporal lesion.

A relevant impact of the task used to investigate noun and verb processing in the brain is also revealed by the studies using repetitive transcranial magnetic stimulation (rTMS). Shapiro et al. (2001) found that a prefrontal stimulation causes increased response latencies for verbs but not for nouns; by contrast, in another study Cappa et al. (2002) obtained the opposite (facilitation) effect in an action naming task after stimulating over the same region. The opposite results could be explained by the fact that in the former study patients were asked to carry out a morphological task, while in the latter they had to name pictures; however, this would indicate that frontal regions are crucial for inflecting verbs, but not for retrieving them, the second part of the statement being in overt contrast with most fMRI and PET evidence. Oliveri et al. (2004) conducted a further rTMS study, in which the left primary motor cortex was found to have a critical role in the retrieval of action words irrespective of their grammatical class (i.e. both for nouns and verbs); here again, the task was to inflect a visually presented word according to a symbolic cue indicating if the verb/noun had to be produced in the singular or plural form.

To sum up, the evidence obtained so far in neuroimaging, anatomo-correlative and TMS studies on the brain areas underlying noun and verb processing is rather controversial. This seems to be mostly due to the fact that (i) imageability has been frequently neglected in brain imaging studies and (ii) different experimental and baseline tasks have been used in different experiments, often without a fine-grained analysis of the cognitive processes under investigation. In the fMRI study reported in Chapter 4, we will address these two problematic issues raised by the literature review. Imageability will be taken into account; moreover, we will use two different tasks tapping on the same cognitive process in order to check for the across-tasks reliability of the activations found. In other words, we will try to disentangle task-independent from task-dependent grammatical class effects.

The main rational of the present work and the organization of the dissertation

As emerged from the evidence described so far, theoretical linguistics offers a number of aspects under which nouns and verbs do differ. This suggests that the grammatical class information is represented in the mental lexicon. Nevertheless, neuropsychological, psycholinguistic and neurophysiologic studies on the noun-verb dichotomy did not yield a well-defined corpus of results: it is not clear, for example, at which linguistic stage nouns and verbs are represented separately, and whether different neural circuits underlie the processing of these two grammatical classes.

The work included in this dissertation aims at addressing these issues. In Chapter 2, the spontaneous speech of noun-verb-dissociated patients will be analyzed in order to clarify the nature of the cognitive damage underlying the predominant impairment of either grammatical class. In Chapter 3, psycholinguistic evidence will be provided on how grammatical class information interacts with the processing of morphologically complex words. Finally, in Chapter 4 we will address the neural instantiation of noun and verb processing through a factorial-design fMRI study, which allowed us to distinguish between task-dependent and task-independent grammatical-class-specific activations.

2 NOUN-VERB DISSOCIATION IN APHASIC PATIENTS' SPONTANEOUS SPEECH[1]

INTRODUCTION

Aphasic patients may suffer from disproportionate naming impairment of either verbs or nouns (McCarthy and Warrington, 1985, Zingeser and Berndt, 1988). In the first studies reporting on these patients the grammatical-class-specific deficits were considered as strictly related to the type of aphasia affecting the patients. Disproportionate verb impairment was reported only in non-fluent patients (particularly in agrammatic patients), whereas noun impairment emerged only in fluent patients: as a consequence, these dissociated types of damage were considered as part of the aphasic syndromes and were poorly interpreted in cognitive terms (Zingeser & Berndt, 1990, Myerson & Goodglass, 1972).

More recently verb impairment has been reported to occur also in fluent patients (Berndt, Mitchum, Haendiges & Sandsonn, 1997). For example, in a wide single-case series of patients studied by Luzzatti, Raggi, Zonca, Pistarini, Contardi and Pinna (2002), 9 of the 20 verb-impaired patients were fluent, while 6 were non-fluent, suggesting that both types of aphasia contribute to the same extent to the phenomenon of disproportionate verb impairment. These results clarify that noun and verb impairments cannot be considered just as part of fluent and non-fluent aphasic syndromes; rather, they suggest that different mechanisms may underlie noun-verb dissociation and call for a more specific cognitive analysis of the functional damage(s) generating this phenomenon.

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[1] The present work has been carried out in collaboration with Chiara Ingignoli and Carlo Semenza (Department of Psychology, University of Trieste).

Along these lines, noun-verb dissociation has been interpreted (i) as a consequence of specific syntactic breakdown to functional nodes of the syntactic tree (e.g., Friedmann, 2000), (ii) as an effect of damage to specific subsets of conceptual knowledge, i.e., sensory-visual semantic features (more impacting on nouns) vs. functional semantic features (more relevant for verb; Bird, Howard and Franklin, 2000), (iii) as a by-product of the noun-verb imageability mismatch (Bird et al., 2000) and (iv) as a lexical phenomenon arising either peripherally in the input and output phonological and orthographic lexicons (the *lexeme* level, using psycholinguistic terminology, see Levelt, Roelofs and Mayer 1999; e.g., Rapp and Caramazza, 2002) or at a more central lexical-syntactic storage (the *lemma* level; e.g., Crepaldi, Aggujaro, Arduino, Zonca, Ghirardi, Inzaghi, Colombo, Chierchia and Luzzatti, 2006).

Most of these interpretations are supported by strong evidence and it is likely that each account is correct for some patients, but not for others. A broad and careful neuropsychological investigation seems necessary in order to define case by case the functional damage underlying the same behavioural phenomenon; in fact, each of the four accounts of noun-verb dissociation has some implications that can be verified through neuropsychological testing. Consider for example the case in which the noun-verb dissociation emerges as a consequence of a semantic or syntactic breakdown. On the one hand, following Bird and colleagues (2000), patients with noun-specific impairment due to semantic breakdown suffer from a specific damage to sensory-visual semantic features; consequently, they are expected also to perform worse when naming living things than tools. Vice versa, verb-impaired patients with conceptual problems would have a specific damage to functional semantic features; therefore, the predominant verb impairment should be associated with difficulties in naming tools as opposed to living things. On the other hand, according to Friedmann (2000), verb impairment emerging from a pruning of the syntactic tree is expected to be associated with reduced sentence length, tense/agreement dissociation and impaired processing of Wh-questions and passive sentences. All these predictions are very specific and can be easily tested.

On the contrary, it is not easy distinguish between *lemma* and *lexeme* damages. One may argue that modality-by-grammatical-class simple and double dissociations are useful tools to address this issue. Consider for example the logic applied by Rapp and Caramazza (2002) to the semantic/lexical dichotomy. They described a patient (KSR) who was predominantly impaired at retrieving nouns in spoken production and verbs in written production, concluding that this patient's noun-verb dissociation could not be arising from a semantic damage; in fact, conceptual damage should cause a noun-verb dissociated pattern that is identical across modalities, as both written and oral production are sub-served by the same semantic system. Although this is certainly correct, it is not sufficient to conclude that KSR's damage lies at the lexical level. Indeed, KSR's modality-by-grammatical-class dissociation may have emerged from grammatical-class-specific damage to the semantic-lexical interface, i.e., an impairment in the connections between the semantic system and the peripheral lexicons (see Figure 1a). The same consideration can be generalized to the *lemma-lexeme* dichotomy, when one considers the model of speech production described by Levelt and colleagues (1999). As the lemma level sub-serves both oral and written lexical production exactly as the semantic system (see Figure 1b), a KSR-like performance can of course be used to conclude that the lemma level is preserved, but does not imply that the grammatical-class-specific impairment has to be placed at the lexeme level.

The neurolinguistic studies conducted so far on noun-verb dissociation have focused quite exclusively on formal tasks like picture naming, sentence completion, word naming and written naming, and have generally ignored the assessment of the dissociation in spontaneous speech. Indeed, several studies have reported that agrammatic patients are very poor in verb production in their narrative speech (e.g., Saffran, Berndt and Schwartz, 1989, Thompson, Shapiro and Schendel, 1994, Guasti and Luzzatti, 2002). These results support the hypothesis that verb-impaired agrammatic patients show verb-specific problems also in their spontaneous speech (see also Druks and Carroll, 1995); however, participants in these studies were not tested with picture naming task and we cannot be sure that they were verb-impaired according to the traditional definition.

Bastiaanse and Jonkers (1998) conducted a group study on eight verb-impaired anomic and eight verb-impaired agrammatic patients, explicitly comparing the performance on object/action picture naming task to the verb production profile shown by the patients in spontaneous speech. Considered as a group, both agrammatic and anomic patients performed better with nouns than with verbs in the picture naming task. Moreover, both groups showed a lower-than-normal verb type/token ratio in spontaneous speech: the verb impairment detected in picture naming also emerged in patients' spontaneous speech as a reduced lexical diversity of the verbs produced. However, the type/token ratio did not correlate with the percentage of verbs correctly retrieved in the picture naming task: the authors considered this result as a consequence of a trade-off between lexical richness and morpho-syntactic accuracy. Although it provides interesting evidence on patients' verb production in spontaneous speech, Bastiaanse and Jonkers's study has some limitations. First, it considers patients' performance only at a group level, while there is clear evidence that different functional damage may underlie verb impairment in different patients, even for those suffering from the same type of aphasia (see above). Moreover, as in the previous studies on aphasic patients' spontaneous speech, only verb production was analyzed.

In line with the results obtained by Bastiaanse and Jonkers (1998) and by many other researchers in the past years (e.g., Harris Wright et al., 2003), particular attention will be paid in the present study in differentiating lexical productivity, i.e., the general ability to produce words in spontaneous speech, and lexical diversity, which instead refers to the wideness of the patients' lexicon. Lexical productivity is reflected by the overall number of words (*tokens*) produced by patients in their spontaneous speech; on the contrary, lexical diversity emerges in the number of different lexical forms (*types*) used by patients in their narrative samples (see

Templin, 1957). It must be considered, however, that a high number of types may reflect the production of several different inflected forms of the same lexical entry - *borrowed* is in fact a different type from *borrows*, but they are both inflected forms of the same lemma, *borrow*; this could result in fluent patients having a higher type production than non-fluent patients just because they tend to be morphologically spared, as opposed to non-fluent patients (e.g., Butterworth, 1979, Luzzatti and De Bleser, 1996). A more precise measure of the extent of patients' lexicon is thus the number of different lexical entries produced in speech, irrespective of the inflection taken (*the stem count)*. The number of tokens, types and stems will be considered and analyzed separately in the present study, as the different functional damages underlying noun-verb dissociation might let this phenomenon emerge just with some count methods, but not with others.

Aims of the study

The present study aims at assessing the emergence of the noun-verb dissociation in aphasic patients' spontaneous speech. Moreover, we will investigate whether the analysis of spontaneous speech can shed light on the functional damage underlying the dissociated performance shown by patients in single-word retrieval, with particular focus on the distinction between *lemma*, *lexeme* and *lemma-lexeme* interface impairment.

MATERIALS AND METHODS

Subjects

Seven Italian mild-to-moderate aphasic patients gave their informed consent to participate in the study. They all suffered from a cerebro-vascular attack occurred 6 to 30 months before their spontaneous speech was evaluated. All patients were right handed and their mean age and education were 36 and 11 years respectively (see Table 1). Type and severity of aphasia were assessed by means of the Italian version of the Aachen Aphasia Test (AAT: Luzzatti et al., 1987): five patients suffered from a fluent form of aphasia (three from Wernicke's aphasia, two from anomic aphasia), while two patients suffered from agrammatic non-fluent aphasia.

Preliminary condition for inclusion in the study was a predominant noun or verb impairment in single-word retrieval; this was tested through a noun and verb picture naming task (Luzzatti et al., 2002). The fluent patients split into two groups: three had a significantly better performance in naming action than objects, while the opposite pattern of impairment was found in the remaining two patients. Both agrammatic non-fluent patients suffered from predominant verb impairment (see Table 1).

Narrative samples collection

Patients' spontaneous speech was collected through a semi-structured interview on how their language problems started, on their linguistic problems at the moment of the interview, on their family, on their work and on their hobbies. Patients were left as free as possible to express themselves; the interviewer intervened only to redirect patients when the conversation fell outside the topic or when patients could not communicate their thoughts appropriately.

Narrative samples analysis

Narratives were transcribed and a sample of about 300 words was considered for each patient, according to the principles described by Semenza, Panzeri and Re (1989; see also Vermeulen, Bastiaanse and van Wageningen, 1989). The samples collected for the two non-fluent agrammatic patients FC and LZ were somewhat shorter (143 and 209 words respectively) since they could not produce a three-hundred-word narrative sample in a reasonable amount of time. Moreover, following Semenza et al. (1989), we did not break up sentences at the end of the samples; therefore, the length of the narratives considered could slightly vary around 300 also for fluent patients.

The following variables were calculated for each patient's sample: (i) number of nouns (ii) number of open-class verbs, (iii) number of closed-class verbs, (iv) overall number of open-class items and (v) overall number of closed-class items. In computing these values, we considered as open-class items all nouns, lexical verbs, adjectives and adverbs that are derived from adjectives (e.g., *veloce*$_{ADJ}$-*mente*$_{ADV}$, quick$_{ADJ}$-ly$_{ADV}$). Closed-class words included copulae, auxiliaries, articles, prepositions, numerals, pronouns, possessives, adverbs not derived from adjectives (e.g., *spesso*, often), and conjunctions.

Three different counting procedures were used:

- Items were first counted taking into account any token (*token count*) irrespective of whether it had already been produced either in its base form or in any morphologically related form; for example, *mangiare*, to eat, appearing twice and *mangia*, he eats, produced once would determine a verb token count of three.
- The second count (type count) focused more on lexical diversity of narratives than on productivity, i.e., the number of words in the five categories considered was computed by counting only the first occurrence for each token;
- The third count (stem count) only considered the first occurrence of each individual lexical entry irrespective of the inflection taken; in the example above this would be just one.

Statistical methods

To comply with the norms reported in Semenza et al.'s study (1989), the total number of instances in each class was divided by the total number of words in the sample (making the variables computed as percentages instead of raw counts).

As there is no reason to believe that patients suffering from the same dissociation and the same type of aphasia may suffer from the same underlying functional damages, we analyzed the results considering each single patient as a single case. In order to compare the profiles obtained by the single patients with the normal speakers' performance, we used the modified t-test described in Sokal and Rohlf (1995), which makes use of a more reliable estimate of the population variance than the classical t-test.

RESULTS

Tables 2 and 3 reports on the token, type and stem profiles obtained by the patients for nouns, open and closed-class verbs and open and closed-class elements. Figure 2, 3 and 4 represent the pattern of performance obtained by the verb-impaired non-fluent patients, the verb-impaired fluent patients and the noun-impaired fluent patients.

Single patients' profiles

The agrammatic patients LZ and FC produced significantly less closed-class items than normal controls, as revealed by the token and stem counts for LZ, and by the type count for FC; these patients also had a higher rate of open-class elements than normal controls, arguably as a consequence of their reduced number of closed-class words, closed- and open-class words being in complementary distribution. LZ and FC were also expected to produce less verbs than normal controls in their spontaneous speech: they actually produced a lower-than-normal amount of verb tokens, types and stems, but only LZ's verb-type rate was significantly lower than the mean rate obtained by normal controls. On the other hand, they showed a higher rate of nouns in their speech as revealed by the token, type and stem counts. Altogether, these patients had a spontaneous speech that was constituted quite exclusively of nouns.

The verb-impaired fluent patient UB had a reduced production of open-class elements; again, the complementary result of a higher-than-normal rate of closed-class items is arguably a purely mathematical side-effect. He also showed an unexpected pattern in noun and verb production: performing worse at actions than at objects in the picture naming task, he had a lower-than-normal noun rate in the token count and a higher-than-normal verb rate in the type and stem counts.

The verb-impaired fluent patient MC did not show any abnormal peak in his open- and closed-class item production as compared to normal speakers. He also showed a higher-than-normal production of verbs in the token and type counts (but not in the stem count): again, a paradoxical pattern emerged that is characterized by verb production impairment in picture naming and larger production of verbs than normal controls in spontaneous speech. It is worth to note though that MC's performance showed just a trend towards increased verb production in the stem count, thus suggesting that his overproduction of verbs was mostly due to a large retrieval of several different inflected forms of a limited number of lexical entries.

Noun-impaired fluent patient DM showed a reduced production of open-class elements. Moreover, this patient had a significantly lower noun-type rate than normal controls and was consistently below the mean performance of normal controls in the token and the stem counts. DM also showed a greater-than-normal amount of closed-class verb tokens, arguably because she produced a great number of sentences as a consequence of the logorrhoea that typically characterize fluent patient.

GDP, who suffers from non-fluent aphasia and is noun-impaired in picture naming, had a lower-than-normal rate of open-class elements. He showed similar results to patient DM in that he produced considerably less nouns than normal speakers; however, he also produced much more open-class verbs than normal controls.

Completely different results characterized the fluent noun-impaired patient PV. He did not show any abnormal peak in his open- and closed-class item production as compared to normal speakers and he was similar to the other fluent patients in that he showed a higher-than-normal rate of closed-class verbs; however, his overproduction of verbs also extended to open-class verbs, whereas he lay in the normal range for what concerns the production of nouns.

Analysis by type of apahsia

The aphasic patients showing disproportionate verb impairment in the picture naming task clearly split into two groups when their spontaneous speech was analyzed. The agrammatic patients suffered from reduced open-class verb production, particularly when lexical diversity was considered: FC produced significantly less verb types than normal matched controls (Table 2 and Figure 2) and LZ showed a clear trend in the same direction ($t = -.85$; $p < .25$; see Table 2 and Figure 2). On the contrary, the verb-impaired fluent patients had no difficulty in producing open-class verbs: they even showed a higher-than-normal rate of open-class verbs in their speech in the token (MC), type (UB and MC) and stem count (UB; see Table 2 and Figure 3). For what concerns the three noun-impaired patients entering the present study, two of them (DM and GDP) produced less noun types than normal controls, i.e., showed a reduced noun diversity in their spontaneous speech (Figure 4). On the contrary, PV did not show any reduction of noun diversity in his speech; the opposite trend emerged instead, since his noun-stem rate was just above the significance threshold ($t = 1.54$, $p < .10$; see Table 2 and Figure 4).

DISCUSSION

Most of the studies reporting on aphasic patients suffering from grammatical-class-specific lexical impairment have focused on formal tasks, like picture naming, sentence completion and word naming, and did not test noun-verb dissociation in speech samples. Bastiaanse and Jonkers (1998) did analyze the spontaneous speech of anomic and agrammatic verb-impaired patients, but restricted their attention just on verb production. Altogether, there is no general picture of whether/how grammatical-class-specific impairments emerge in spontaneous speech. In the present study we address this issue by anayzing narrative samples of a wide range of aphasic patients, i.e., verb-impaired non-fluent patients, verb-impaired fluent patients and noun-impaired fluent patients.

Verb-impaired non-fluent patients

Consider first the overall verb production as indicated by the token count. The verb-impaired non-fluent patients entering this study do not differ significantly from normal controls; they show a trend toward a reduced token production though. These patients also show a reduced production of open-class verb types: LZ's performance is significantly lower than that of normal controls and FC shows a non-significant trend in the same direction. These patients are also very poor in closed-class item production, both in terms of general productivity (token count) and in terms of lexical diversity (token and stem counts).

This pattern is not surprising as the association between a greater impairment on verbs than nouns and on closed-class words than open-class words is frequently reported in non-fluent agrammatic patients (e.g., Bradley, 1978, Bradley et al., 1980); this has been rarely reported in patients' spontaneous speech tough (Goodglass et al., 1994). This pattern suggests the presence of a relatively deep lexical damage, which is likely to involve the lexical-syntactic interface (i.e., the *lemma* level, see Levelt et al., 1999) rather than the peripheral phonological lexica (the *lexeme* level, see Levelt et al., 1999). A verb-specific damage affecting this functional level explains the poor verb diversity shown by these patients in their connected speech: having problems at the lemma level, their lexical difficulty would become even more severe when they are required not only to name action pictures, but to produce complete and connected sentences; this in fact requires the patients to recover the syntactic information associated with the lexical at the lemma level (e.g., the grammatical gender of nouns for article-noun and adjective-noun agreement, the thematic grid of verbs to set up the syntactic tree correctly).

This functional interpretation of the damage is also in line with LZ's brain lesion (the CT scans of FC were not available to the authors). This patient suffered a stroke involving the territory of the left middle cerebral artery, causing a massive fronto-temporo-parietal infarct that affected the whole left perisylvian cortex and the underlying white matter. In this situation it is likely that the linguistic ability of the right hemisphere comes into play (Vitali et al., 2007, Breier et al., 2007, Perani et al., 2003) and this has been repeatedly demonstrated to be limited to phonological information, particularly of high-frequency concrete nouns (e.g., Zaidel, 1990, Coltheart, 2000, Sereno, 1999): this pattern is straightforwardly interpretable as reflecting a linguistic system lacking of a lemma level.

Verb-impaired fluent patients

Patient UB shows a trend toward a higher-than-normal verb token production, while MC clearly makes use of more verb tokens in his speech than normal controls. The verb overproduction shown by the verb-impaired fluent patients may actually be surprising; nevertheless, Bastiaanse and Jonkers (1998) reported that verb-impaired patients (either fluent or non-fluent) show a reduced type/token ratio in their speech, rather than an overall reduction of the raw number of verbs: according to these authors, the verb lexical diversity – and not the verb lexical productivity – would thus be affected in the patients' connected speech. Along these lines, we turn our attention to the verb type production. The pattern of performance emerging in fluent patients is radically different from that shown by verb-impaired non-fluent patients; both MC and UB have an open-class verb-type rate that is higher than that of normal controls, thus showing an even higher-than-normal verb diversity in their spontaneous speech. This pattern cannot be explained by the fluent patients' spared ability to generate different inflected forms of the same lexical entry[2] since both patients also have a high verb-stem rate in their speech samples: this clearly indicates that UB's and MC's high verb-type rate truly reflects a (higher-than-)normal lexical diversity and not just a high "inflectional productivity".

Altogether, these patients show a different pattern as compared to non-fluent verb-impaired patients: in spontaneous speech they seem to overcome the verb-specific problems emerging in picture naming. This different pattern of performance observed in single-word retrieval and connected speech cannot be interpreted in terms of a lemma-level damage since, in this case, we would expect these patients to show verb-specific impairment also in connected speech (like the non-fluent verb-impaired patients). Likewise, there is no reason to hypothesize that these patients suffer from a damage to the lexeme level: also in this case we would expect that the grammatical-class-specific impairment emerging in picture naming would emerge in spontaneous speech as well. The different performance between single-word retrieval and connected speech can instead be explained by a verb-specific impairment in activating lexeme representations from an unimpaired lemma level. With such a functional damage, patients are in fact expected to fail in naming picture of verbs: they would access the lemma of the target word (i.e., grammatical class and syntactic features), but could not retrieve the phonological form of the target word (the *lexeme*). On the contrary, a verb-specific functional damage to the lemma-lexeme interface may not determine a greater difficulty in producing verbs in spontaneous speech; in analogy with what is suggested by Crepaldi and colleagues (2006), the spontaneous speech richer (syntactic and communicational) context and the presence of sentence frames determining a syntactically structured linguistic environment may boost the activation of the preserved lemma-level information, thus determining an easier access to the phonological verb forms. This

[2] In Italian a same verb stem can be produced in more than 40 different inflected forms, so that it is possible for patients without morphological impairment to reach a very high type count making use of few stems.

context-mediated lemma-boost mechanism could thus facilitate patients' verb retrieval in connected speech as compared to isolate-word retrieval.

Noun-impaired fluent patients

In two out of three patients with noun impairment in picture naming task, a noun-specific problem also emerges in connected speech. DM and GDP have both a quasi-significant lower production of nouns, as indicated by the token count. In addition, both the type and the stem counts indicate that these patients are significantly lower than normal controls as far as noun diversity is concerned. In other words, these patients make use of less nominal lexical entries in their speech than normal controls and do not compensate this deficit by producing different inflected forms of these few lexical entries. PV shows instead a different pattern; he does not have a reduced noun production in his connected speech in all three count types.

GDP's and DM's performance can be explained in principle by both lemma-level and lexeme-level noun-specific impairment. A lemma-lexeme interface problem cannot be excluded either. In fact, nouns play a much less crucial syntactic role than verbs and the lemma-level information can be considered to be less important for noun retrieval than for verb retrieval; as a consequence, the syntactic context characterizing spontaneous speech is less likely to facilitate the access to noun lexemes in patients suffering from noun-specific impairment affecting lemma-lexeme-interface. The significant overproduction of closed-class items and of closed-class verbs (a performance also emerging for PV, the noun-impaired patient whose pattern of performance is inconsistent with that emerging for GDP and DM) suggests that the lemma level is spared in these patients; this would also be in line with the type of aphasia they suffer from. However, a neat distinction between lexeme damage and lemma-lexeme interface damage appears to be impossible in noun-impaired patients if we only rely on spontaneous speech analysis.

Patient PV does not have any particular difficulty in producing nouns in his speech sample; he shows instead a trend toward a higher-than-normal lexical diversity as revealed by the stem count. Moreover, PV had a normal distribution of open- and closed-class words in his speech, while GDP and DM showed a remarkable overproduction of closed-class words as compared to open-class words, particularly in the type and stem counts: this is likely to reflect PV's normal production of nouns. PV also produces a higher number of open-class verb tokens and types; the same pattern also emerges for closed-class verbs. Altogether, being his production of nouns, open-class verbs and closed-class verbs within the normal range, PV's speech turns out to be particularly poor in non-verbal closed-class elements like, e.g., articles, prepositions and non-lexically-derived adverbs; this arguably reflects functional damages that lie outside the lexicon. In other words, PV's spontaneous speech seems to be not particularly informative on the functional damage underlying his noun-specific impairment. However, it remains to be explained why the noun impairment shown by PV in picture naming does not correspond to a similar damage in connected speech as it is the case for the patients GDP and DM.

CONCLUSIONS

Notwithstanding the considerable effort put in the last twenty years toward the comprehension of grammatical-class-specific lexical impairments, it is not clear yet whether these deficits emerge also in aphasic patients' spontaneous speech. The analysis of speech samples shown by seven verb- and noun-impaired patients reported in the present study has suggested that:

(i) Lexical impairments that predominantly involve nouns or verbs may also emerge in patients' connected speech either as a reduced overall productivity or as a lower-than-normal lexical diversity; however, this does not occur systematically, but depends on the underlying cognitive damage and/or on the type of aphasia the patients suffer from.

(ii) The verb production pattern emerged in the spontaneous speech of verb-impaired non-fluent patients suggests that they suffer from a verb-specific damage at the lemma level; this is further confirmed by the brain lesion characterizing LZ and is arguably related to the emergence of right hemisphere lexical ability.

(iii) Fluent verb-impaired patients are likely to suffer from a lemma-lexeme interface damage; this functional deficit allows these patients to overcome their verb-specific damage in connected speech, arguably because this is highly structured from a syntactic point of view and thus determines an activation boost of the preserved lemma-level information.

(iv) The analysis of the spontaneous speech shown by noun-impaired aphasic patients does not allow to clearly identify the underlying cognitive damage; these patients may suffer either from a pure lexeme-level impairment or from a lemma-lexeme interface damage.

Finally, the present study has highlighted the importance of using different counting methods when analyzing aphasic patients' spontaneous speech; while some deficit may emerge in terms of a lower-than-normal token production (i.e., lexical productivity), others can only be appreciated when the production of types and stems is considered (i.e., lexical diversity).

TABLES AND FIGURES

Table 1. Patients' data with respect to age, education, aetiology, time post-onset (months), type of aphasia and performance obtained in the preliminary picture naming task (the percentage of correct responses is reported).

							Picture naming task	
N°	Pt	Age	Education	Aetiology	Months post-onset	Type of aphasia	% N	% V
1	LZ	36	15	Aemorrhagic	24	Broca's agrammatic	70	38
2	FC	21	15	Ischaemic	6	Broca's agrammatic	87	30
3	UB	49	8	Ischaemic	30	Wernicke's	87	48
4	MC	35	8	Head injury	13	Wernicke's	73	8
5	DM	18	11	Head injury	12	Anomic	13	38
6	GDP	53	8	Ischaemic	11	Wernicke's	13	40
7	PV	42	13	Aemorrhagic	18	Anomic	13	58

Table 2. Patients' profiles for the production of closed-class verbs, open-class verbs and nouns in spontaneous speech. The stem values for closed-class verbs are omitted because in Italian there are only two verbs (essere, to be, and avere, to have) that can be used as copulae or auxiliaries.

*Legend. PNT, noun-verb dissociation as revealed by the picture naming task, Pt, patient initials, AT, aphasia type, Count, cont type, %, percentage of item on the total number of words, T value, modified t-value (Sokal and Rohlf, 1995), *, statistically significant at p<.05, **, statistically significant at p<.005.*

				ClosedClassVerbs		OpenClassVerbs		Nouns	
PNT	Pt	AT	Count	%	T value	%	T value	%	T value
N>V	LZ	Ag	Token	2	-1.42	14	-0.46	33	4.80**
			Type	4	0.12	17	-1.70*	51	9.06**
			Stem			14	-1.29	46	5.04**
	FC	Ag	Token	2	-1.42	15	-0.46	33	4.80**
			Type	2	-1.63	19	-0.85	44	6.91**
			Stem			16	-0.30	46	5.20**
	UB	Flu	Token	5	0.36	17	1.24	12	-2.09*
			Type	5	0.73	29	3.22**	22	-0.56
			Stem			23	1.83*	26	-0.42
	MC	Flu	Token	6	0.67	24	5.00**	19	0.09
			Type	7	2.27*	29	3.38**	21	-1.01
			Stem			21	1.37	32	1.21
V>N	DM	Flu	Token	9	2.28*	15	0.12	13	-1.62
			Type	5	0.80	22	0.55	17	-2.48*
			Stem			18	0.32	22	-1.59
	GDP	Flu	Token	18	7.30**	24	5.28**	13	-1.62
			Type	11	5.23**	29	3.17**	13	-3.55**
			Stem			23	2.10*	15	-3.37**
	PV	Flu	Token	8	1.92*	19	2.51*	19	0.39
			Type	7	2.76**	27	2.56*	26	0.80
			Stem			19	0.72	33	1.54

*Table 3. Patients' profiles for the production of closed-class and open-class words in spontaneous speech. Legend. PNT, noun-verb dissociation as revealed by the picture naming task, Pt, patient initials, AT, aphasia type, Count, cont type, %, percentage of item on the total number of words, T value, modified t-value (Sokal and Rohlf, 1995), *, statistically significant at p<.05, **, statistically significant at p<.005.*

				OpenClassWords		ClosedClassWords	
PNT	Pt	AT	Count	%	T value	%	T value
N>V	LZ	Ag	Token	47	2.44*	52	-
			Type	57	0.42	41	-1.13
			Stem	62	1.11	36	-1.69*
	FC	Ag	Token	45	1.59	55	-1.59
			Type	63	2.21*	37	-2.12*
			Stem	63	1.34	37	-1.34
	UB	Flu	Token	29	-3.54**	70	3.18**
			Type	51	-1.41	47	0.85
			Stem	48	-2.03*	49	1.51
	MC	Flu	Token	39	-0.13	60	-0.12
			Type	51	-1.46	48	1.01
			Stem	54	-0.67	44	0.12
V>N	DM	Flu	Token	29	-3.27**	70	3.27**
			Type	40	-4.67**	60	4.57**
			Stem	42	-3.50**	58	3.50**
	GDP	Flu	Token	40	-0.07	60	-0.10
			Type	43	-3.85**	56	3.51**
			Stem	40	-4.09**	61	4.09**
	PV	Flu	Token	39	-0.29	60	-0.05
			Type	54	-0.45	43	-0.26
			Stem	53	-0.84	43	0.04

Figure 1. Possible interpretation of noun-verb written-oral double dissociation, with particular reference to the semantic system (a), or to the lemma store (b).

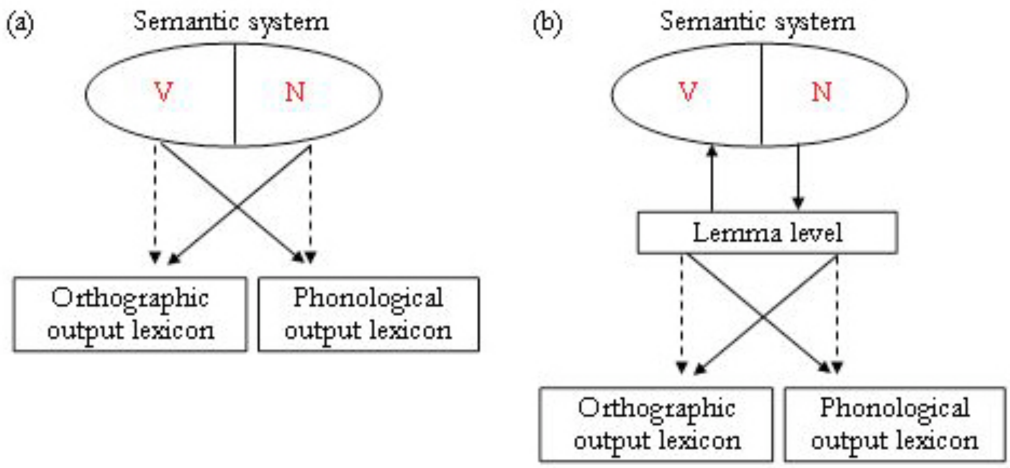


Figure 2. Non-fluent verb-impaired patients' verb production profiles as compared to the mean profile of Italian normal speakers. The full line represents normal controls, the dashed line represents LZ's profile and the dotted line represents FC's

profile.

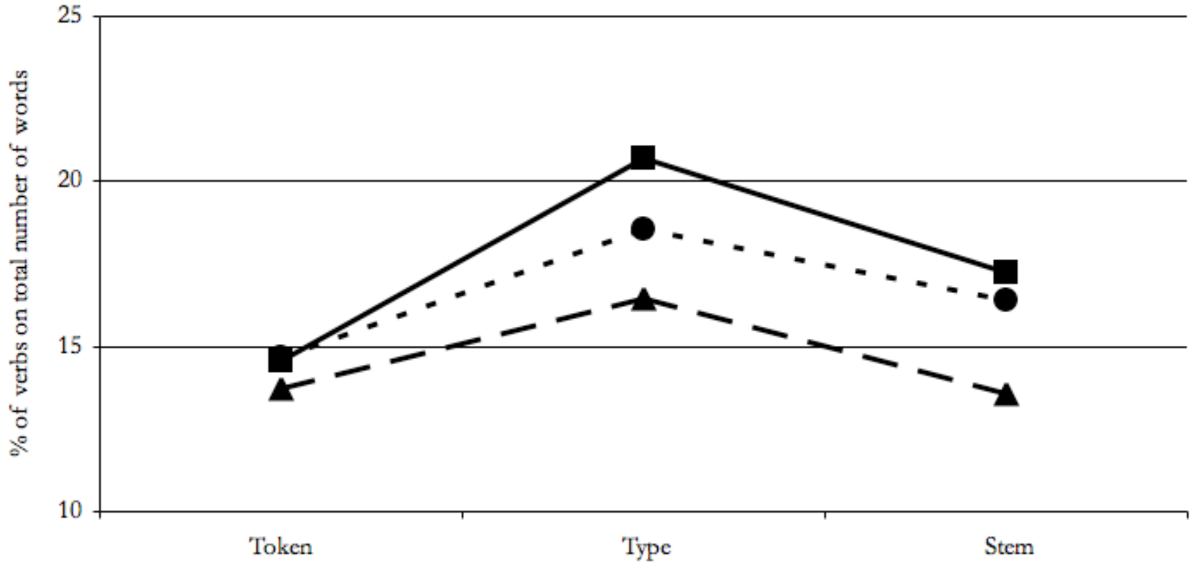


Figure 3. Fluent verb-impaired patients' verb production profiles as compared to the mean profile of Italian normal speakers. The full line represents normal controls, the dashed line represents UB's profile and the dotted line represents MC's profile.

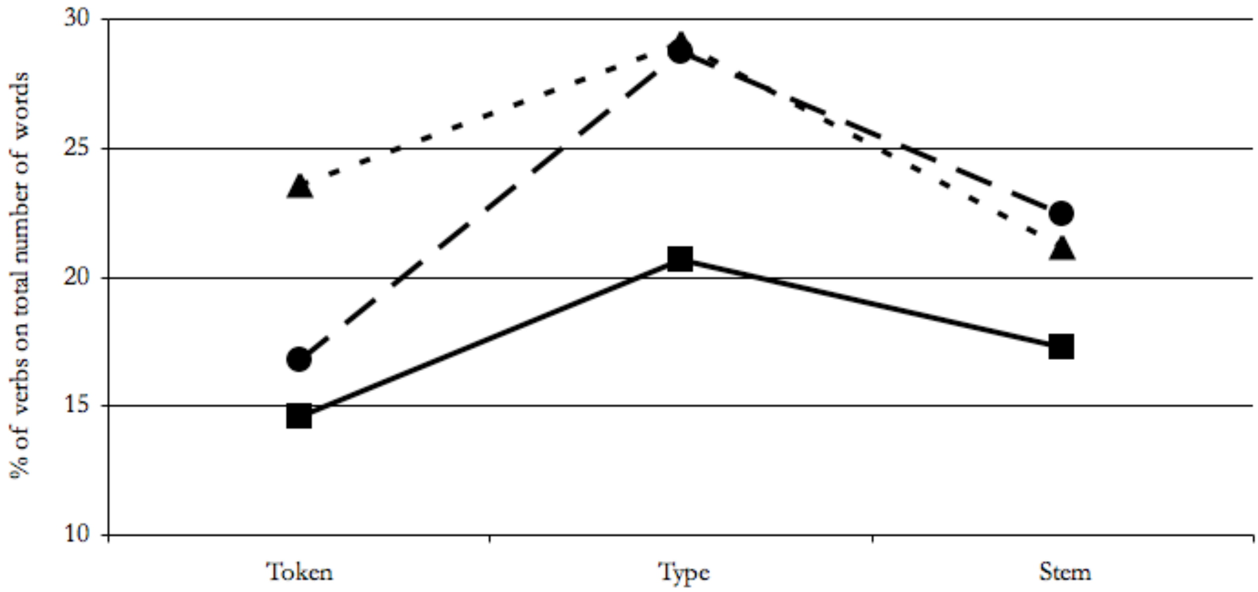
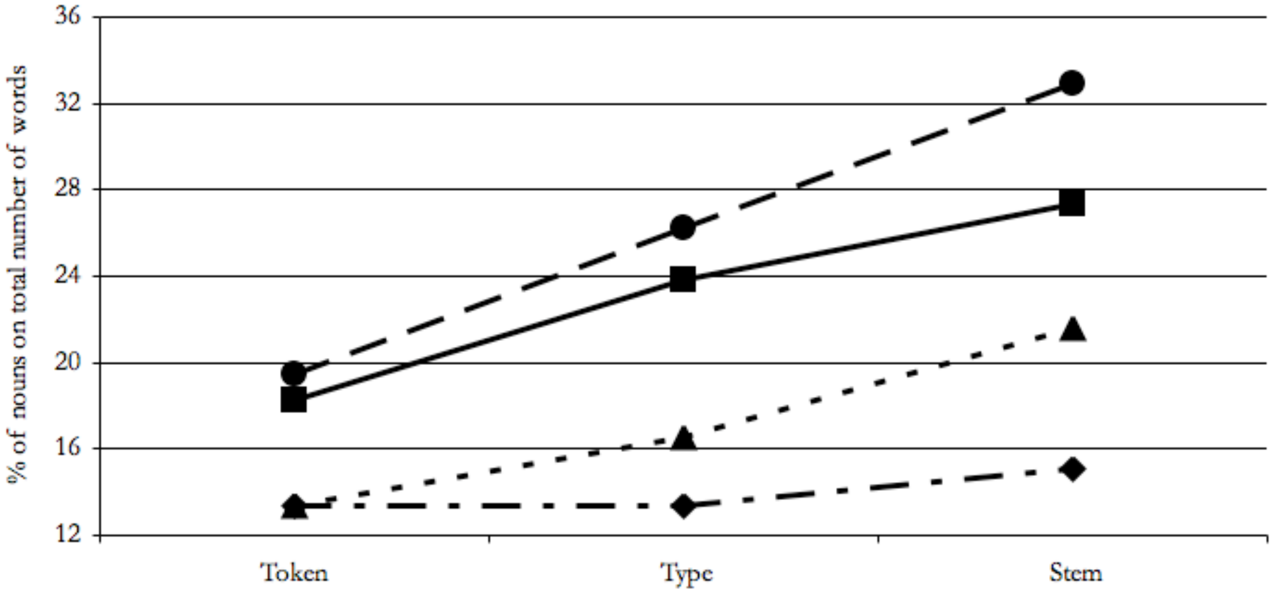


Figure 4. Fluent noun-impaired patients' noun production profiles as compared to the mean profile of Italian normal speakers. The full line represents normal controls, the dotted line represents DM's profile,the dash-dot line represents GDP's profile and the dashed line represents PV's profile.



3 MENTAL REPRESENTATION OF NOUNS AND VERBS: GRAMMATICAL CLASS AND PRIMING EFFECTS[1]

INTRODUCTION

In the literature on word recognition it is often assumed that words that are close together in the mental space tend to overlap in terms of orthographic, phonological and semantic components (e.g., Rueckl, 2002) and one of the most promising methods to investigate the properties of this space is the priming paradigm.

A debate in psycholinguistics concerns the nature of multimorphemic word representation and mental processing; there are different positions regarding whether morphologically complex words are represented and accessed in terms of their constituent morphemes (e.g., Taft & Forster, 1975) or whether morphological decomposition play a backup role in lexical processing (e.g., Butterworth, 1983).

Priming experiments conducted so far have shown that the presentation of a morphologically related prime facilitates the processing of the target word. This phenomenon has been shown for different languages (e.g., English: Stanners, Neiser, Hernon, & Hall, 1979; Fowler, Napps, & Feldman, 1985; Feldman, 1992; Hebrew: Bentin & Feldman, 1990; Spanish: Rodriguez-Fornells, Munte and Clahsedn, 2002) and for different word recognition tasks. Moreover, there is much evidence which indicates that morphological priming differs from purely orthographic and semantic priming, in that it

1 The present work has been carried out in collaboration with Lisa Saskia Arduino (Department of Psychology, University of Urbino and Institute for Cognitive Science and Technology, National Research Council, Rome).

produces stronger and longer facilitation than semantic priming does, whereas orthographically related primes tend to result in inhibition (Drews & Zwitserlood, 1995; Feldman, 2000).

Rastle, Davis, Marslen-Wilson, and Tyler (2000) examined morphological, semantic, and orthographic priming by using a masked priming procedure with different intervals between the presentations of the prime and the probe (Stimulus Onset Asynchrony, SOA; 43, 72, and 250ms). The authors found that morphologically related, semantically transparent primes (e.g., hunter– HUNT) were as effective as identity primes (hunt–HUNT) at all SOAs. These effects were greater than those found for purely semantically related (e.g., cello–VIOLIN) or purely orthographically related (e.g., electrode–ELECT) primes. They also found priming for semantically opaque, morphologically related primes at the shortest SOA (e.g., apartment–APART), which nonetheless could not be statistically distinguished from the facilitation triggered by purely orthographic primes (e.g., electrode–ELECT). A similar study by Dominguez, Segui, and Cuetos (2002) compared semantic, orthographic, and morphological priming in a lexical decision task in Spanish. At short SOAs (as 64 ms) both the morphological primes and the orthographic primes produced facilitation, but the effect was greater for the morphological primes; in addition, there was no semantic priming effect. However, when the SOA was longer (250 ms) facilitation for the morphological and semantic primes and inhibition for the orthographic primes were found. In line with Rastle et al. (2000), this result provides strong evidence that a morphologically structured level of representation plays an important role in visual word recognition, and suggests that early morphological priming can be obtained independently of semantic relatedness, which should only influence morphological priming at longer prime durations (Marslen-Wilson, Tyler, Wakser & Older, 1994; Feldman, Barac-Cikoja, & Kostic, 2002; Feldman, Soltano, Pastizzo, & Francis, 2004).

Generally, the literature mentioned above has been focusing on nouns and, when different grammatical classes were used (e.g., Forster, 1987; Laudanna, Badecker & Caramazza, 1989; Traficante, Barca & Burani, 2004), this variable was not considered *per se* and/or was not manipulated. However, several sources of evidence have suggested that nouns and verbs are differently represented in the mental lexicon (Levelt, Roelofs and Meyer, 1999) and can be differently impaired after brain damage (e.g., Bird, Howard and Franklin, 2000, Rapp & Caramazza, 2002).

An effect of grammatical class has been reported in a picture-word interference experiment by Mahon, Costa, Peterson, Vargas and Caramazza (2007). These authors showed different effects to emerge when the written distractor word was a verb or a noun; in particular, while semantically related verbs facilitated noun retrieval as compared to unrelated verbs, semantically related nouns inhibited object naming as compared to unrelated nouns. Nevertheless, these results were not explicitly interpreted in terms of grammatical class effects. Rather, the authors suggested that distractor verbs did not slow down object naming because they were not competing with the target nouns for selection, as the task required to name objects, and not actions; in the authors' terminology, distractor verbs did not satisfy the task-determined response relevant criteria. This was supported by the fact that Mahon and colleagues showed this verb-noun effect to be sensitive to imageability (Experiment 3): as noun and verb distractors were lower in imageability (and thus were both non-satisfying the task-determined response relevant criteria), the difference between the two grammatical classes became smaller.

However, while related words belonging to the same grammatical class have been shown to elicit morphological and semantic facilitation effects (within-class priming effects), it is not clear whether the same effects occur between elements belonging to different grammatical classes, like verbs and nouns (cross-class priming effects).

In order to explore whether nouns and verbs prime each other when they are morphologically and/or semantically related, three masked priming experiments have been set up in which the grammatical class of primes and probes was manipulated at different SOAs.

Morphological and semantic priming effects have been studied either in lexical decision (e.g., Rastle et al., 2000) or in reading task (e.g., Tabossi and Laghi, 1992), while in other studies both tasks have been used (e.g., Deutsch et al., 1998). Since we were interested in both peripheral (i.e., orthographic and lexeme) and central (i.e., lemma and semantic) stages of processing, a reading task has been used in the present study as it encompasses all these processing levels. Moreover, making unnecessary non-word control trials, the reading task is less prone to list effects and allows testing written word processing in a situation that is closest to everyday life.

EXPERIMENT 1

A theoretical issue that is still open to debate and for which the investigation of cross-class morphological priming may be relevant is the representation and processing of roots that sub-serve the formation of both nouns and verbs (e.g., *depart-* in *depart*-ure and *depart*-s). Although grammatical class is universally recognized as a crucial factor in most speech production models (e.g., Levelt et al., 1999), a few studies have addressed the interaction between grammatical class and priming effect while investigating written word comprehension. Frost, Deutsch and Forster (1997) and Deutsch, Frost and Forster (1998) conducted a study in Hebrew in which both reading aloud and written lexical decision tasks have been used; however, these authors tested within-class morphological priming emerging with noun-noun and verb-verb prime-probe pairs, but did not investigate cross-class morphological priming effects. [Frost et al. (1997) have shown that morphological facilitation is observed between nouns only when these have the same root (e.g., *zmr*, as in *z*a*m*i*r*-ti*zm*o*r*et), but not when primes and probes share their inflectional pattern (e.g., *ti_ o_et*, as in *ti*ksh*o*r*et-ti*zm*o*r*et*). By contrast, Deutsch et al. (1998) have shown that morphological priming emerges between verbs both when primes and probes share the root and when they share just the inflectional pattern. Deutsch and colleagues (1998) interpreted their results in terms of semantic transparency and frequency of occurrence rather than as due to grammatical class *per se*; nevertheless, they developed a model in which nouns and verbs share the representation of their common roots; cross-class morphological priming is readily expected thus if the model proposed by Deutsch et al. is correct.

In order to test this hypothesis, a masked priming experiment has been set up in which Italian primes and probes share their root and belong to a different grammatical class (noun or verb). A shared root generally implies semantic relationship (e.g., 'depart' and 'departure' are both morphologically and semantically related); as we wanted to assess morphological and semantic effects independently, a condition in which primes and probes were only semantically related (e.g., *baciare-amore*, to kiss-love$_N$) has been included in the design. Finally, two different SOAs have been used in order to track the temporal pattern of the cross-class priming effects.

Materials and Methods

Participants

Sixty-one right-handed undergraduate students at the University of Milano-Bicocca participated in Experiment 1; they were all volunteers, had normal or corrected-to-normal vision, were Italian native speaker and had no history of neurological disorders or learning disabilities. Forty-two of them were females and nineteen were males; their mean age was 23 (range: 19-33).

Materials

The list was composed by 45 Italian verbs and their 45 corresponding nouns (e.g. *applaudire* and *applauso*, ‘to applaud’ and ‘applause’) that were selected from the set used by Crepaldi et al. (2006): noun and verb in each pair were both morphologically and semantically related. The orthographic transparency of the morphological relationship was kept as high as possible: in 32 cases there was no orthographic modification of the root, which took exactly the same orthographic form in both the noun and the verb (e.g., *baci-are,* to kiss, and *baci-o*, kiss$_N$). In the remaining 13 pairs there was an orthographic change of the root, but this was limited to one letter (e.g., *rid-ere* and *ris-ata*, to laugh$_V$ and laugh$_N$) in all but two cases (*raccogli-ere* and *raccol-ta*, to harvest$_V$ and harvest$_N$; *legg-ere* and *lett-ura*, to read$_V$ and reading$_N$).

Twenty-seven verbs belonged to the first conjugation (*-are* verbs; e.g., *saltare*, to jump), 13 verbs to the second conjugation (*-ere* verbs; e.g., *correre*, to run) and five verbs to the third conjugation (*-ire* verbs; e.g., *dormire*, to sleep); this distribution reflects the proportion of the three conjugations in the entire Italian verb set (*-are* verbs=70%; *-ere* verbs=19%; *-ire* verbs=11%; see the BDVDB database, Thornton, Jacobini and Burani, 1997).

As reported in Table 1, nouns and verbs were matched for number of letters, oral word frequency (Laudanna et al., 1995), imageability (estimated on the basis of a sample of 21 normal subjects along a seven-point scale) and age of acquisition. Regarding this latter variable, norms for nouns were taken from Lotto, Dell’Acqua and Job (2001), whereas norms for verbs were collected from a sample of 20 normal subjects using the same methodology adopted by Lotto and colleagues. Verbs have a higher number of syllables and have a significantly higher stem frequency than nouns (Laudanna et al., 1995).

Each of the 45 noun-verb pair was tested in two different conditions: in the NV condition the noun served as prime and the verb as target, while in the VN condition the verb served as prime and the noun as target. Therefore, the 45 noun-verb pairs generated 90 trials, 45 in the NV condition (e.g., *applauso-applaudire*, applause-to applaud) and 45 in the VN condition (e.g., *applaudire-applauso*, to applaud-applause).

As we were interested in disentangling the contribution of the morphological and the semantic relationship, a further set of 90 primes was built up. Each of the 90 targets was paired with a word belonging to the opposite grammatical class that was only semantically – and not morphologically – related (e.g., *applaudire,* 'to applaud', was paired with *teatro*, 'theatre', and *applauso*, 'applause', was paired with *ammirare*, 'to admire'). The strength of the semantic association between primes and probes was estimated by 12 volunteers on a 7-point scale; for both NV and VN conditions, related and control pairs were taken from the extreme (high and low, respectively) tails of the distirbution.

The morphological and semantic sets of primes were then matched pairwise for grammatical class, surface frequency and word length with two independent control sets of words (see Table 2 for a summary of the experimental conditions).

Procedure

Cross-class morphological and semantic priming were tested in Experiment 1 with two different SOAs, 100 ms and 300 ms. In both cases trials began with a crosshair displayed on a computer screen for 500 ms. Then the prime word was presented in lowercase for either 50 or 250 ms, and was immediately followed by a hash-sign mask that remained on the screen for 50 ms. Then the target word appeared in uppercase and the experiment editor application (E-prime 1.1) started the reaction time (RT) measurement. The target word remained on the screen until the subjects' response: if participants did not respond within three seconds, the target word disappeared. Trials were separated by a 1.5-second inter-stimulus interval. All stimuli were displayed in the middle of the screen, in Arial font (size 24) and in black against a white background.

Subjects were instructed to ignore the lowercase words and to read aloud as fast and accurately as possible the stimuli that were displayed in uppercase. Before being presented with the experimental stimuli, participants faced 10 practice trials, which allowed them to familiarize with the task; if the experimenter noticed any sign of misunderstanding of the instructions, the familiarization session was rerun. The experimental session started only when subjects showed a complete understanding of the task by correctly carrying out all the practice trials.

Data collection

Reaction times were measured through a microphone connected to a Serial Response Box controlled by the experiment editor application (E-prime 1.1). The correctness of the responses was judged on-line by the experimenter; nevertheless, experimental sessions were recorded in order to give the experimenter the possibility of a more careful off-line evaluation in case of unclear responses.

Experimental design

In order to avoid targets to be presented twice to any single subject, *prime type* (morphological vs. semantic) was used as a between-subject variable; the same was done for *SOA* (100 ms vs. 300 ms). Four different conditions were thus set up (morphological priming with 100-ms SOA; morphological priming with 300-ms SOA; semantic priming with 100-ms SOA; semantic priming with 300-ms SOA): each participant underwent only one of these conditions. *Prime direction*, i.e. noun primes verb (NV) vs. verb primes noun (VN), and *relatedness*, i.e., related prime vs. control prime, were instead used as within-subject variables. Such an experimental design makes each stimulus appear once as prime and once as target in each condition. In order to minimize the possible confounding effect due to this repetition, the gap between the presentations of the two trials with the same stimulus was maximized.

Moreover, the order of presentation of the trials containing the same stimulus was counterbalanced across subjects within each condition: each stimulus was presented to half of the subjects first as prime and then as target, and to half of the subjects with the opposite order.

Statistical analysis

Data were preliminarily analyzed in order to exclude from the analyses uninformative and artefact-related data-points, keeping the statistical power as high as possible. First, responses with RTs lower than 200 ms or higher than 1200 ms were excluded. Then, the by-subject and by-item data-sets were created; incorrect responses were not considered in the calculation of mean RTs. Finally, in order to make RT distributions more Gaussian-like and thus maximize the statistical power of the analyses, mean RTs were inverse-transformed (see Van Zandt, 2002).

A four-way Analysis of Variance was then carried out on the by-subject and by item data-sets in order to assess main effects and interactions; simple effects were instead calculated through a series of t-tests. In order to better evaluate all these effects, power levels and effect sizes will also be reported.

Results

The percentage of correct responses was at ceiling (98% average in both by-subject and by-item data-sets) and thus accuracy was not analyzed further. The analyses of the RTs showed a significant main effect of *relatedness* (by subjects: $F[1,58]=69.69$; $p<.001$; by items: $F[1,88]=85.39$; $p<.001$), a significant interaction effect of *relatedness* by *prime-type* (by subjects: $F[1,58]=36.35$; $p<.001$; by items: $F[1,88]=63.29$; $p<.001$) and a significant interaction effect of *relatedness* by *prime-type* by *SOA* by *prime-direction* (by subjects: $F[1,58]=5.54$; $p<.05$; by items: $F[1,88]=9.52$; $p<.005$). Table 3 reports the simple effects of relatedness in the eight conditions made up by the other three variables (prime type, SOA and prime direction). Cross-class morphological priming effect is clearly present in any condition. The picture is much less clear when nouns and verbs are semantically related. For the 300-ms SOA, the effect is significant by subjects (NV: $t[31]=1.92$, $p<.05$; VN: $t[31]=2.15$, $p=.01$) and slightly above the significance level by items (NV: $t[44]=1.68$, $p=.06$; VN: $t[44]=1.40$, $p=.09$); there is no difference between the condition in which nouns prime verbs and the condition in which verbs prime nouns. Considering the 100-ms SOA, there is a significant effect when nouns prime verbs (by subjects: $t[31]=2.93$, $p<.01$; by items: $t[44]=2.42$, $p=.01$), but not when verbs prime nouns (by subjects: $t[31]=.58$, $p=.71$; by items: $t[44]=.88$, $p=.80$). In addition, as a further evidence of the interaction between *relatedness* and *prime type* revealed by the ANOVA, the morphological facilitation is significantly higher than the semantic facilitation in any single condition (NV, 300-ms SOA: $t[44]=6.16$; $p<.001$; VN, 300-ms SOA: $t[44]=4.84$; $p<.001$; NV, 100-ms SOA: $t[44]=1.94$; $p<.05$; VN, 100-ms SOA: $t[44]=5.42$; $p<.001$).

Discussion

In line with Deutsch et al.'s (1998) hypothesis, the presence of a cross-class morphological priming effect indicates that homographic stems belonging to different grammatical classes (nouns and verbs in this case) share their representation, i.e., there is a unique representation of the root *appl-,* which is called upon both when *applauso* (applause) and *applaudire* (to applaud) are read by the subjects. A shared morphological representation of homographic roots is further supported by the symmetry of the effect: the facilitation does not change significantly when nouns prime verbs or, vice versa, verbs prime nouns. The cross-class morphological priming does not interact with the SOA; the effects obtained when the prime appears 100 ms or 300 ms before the target are comparable. This suggests that the shared morphological representation is accessed since the very early steps of the word recognition process; if this was not the case and the morphological analysis had come into play later on the process, we would have obtained a priming effect with the longer SOA, but not with the shorter one. We can thus maintain that the morphological structure of the prime words (i.e., the access to the representation of the roots) is already addressed after 100 ms from their presentation; this aspect was not addressed by Deutsch and colleagues (1998). Again, morphological priming is significantly higher than semantic non-morphological priming (*applauso* determines a higher facilitation when reading *applaudire* than *teatro*, theatre). This clearly shows that the morphological effect is genuine and cannot be explained in terms of the semantic relationship primes and probes.

The pattern of results emerged in the semantic condition is much less straightforward. A significant facilitation was found with the 300-ms SOA (significant by subjects and just above the significant threshold by items; see Table 3). The cross-class semantic priming emerging in the present study is comparable to the semantic priming effect found in a reading task by Tabossi and Laghi (1992) with Italian primes and probes belonging to the same grammatical class (e.g., *cane-gatto*, dog-cat, *lampada-luce*, lamp-light); although the effect reported by Tabossi and Laghi (1992) is bigger than that emerging in the present study when difference in means is considered, the effect size is similar. Nevertheless, those authors used an SOA of 500 ms and thus the two studies are not entirely comparable.

By contrast, in the condition in which the SOA was set to 100 ms, the effect depends on the prime direction; in fact, it does emerges when nouns prime verbs, but it does not when verbs prime nouns. We can first exclude that the prime-direction effect arises from an order frequency bias in our material. In none of the noun-verb semantic pairs used in the present study either order is clearly more frequent than the other (e.g., *teatro*, theatre, and *applaudire*, to applaud, do not occur in this sequence more frequently than with the opposite order, *applaudire* and *teatro*): in fact, none of the nouns used in the task was either a semantically or pragmatically natural subject/object of the verb to which it was paired (taking into consideration the example given above, *pubblico*, audience, was not selected as a prime for the verb *applaudire* because 'audience' frequently occurs as the subject of the verb 'to applaud'). Indeed, there seems to be no clear account of the NV-VN asymmetry within the lexical system; if two lexical-semantic nodes are related to each other, it is hard to see how the activation could spread in one direction (in this case, from noun nodes to semantically-related verb nodes giving rise to NV semantic priming), but not in the opposite direction (from verb nodes to semantically-related noun nodes, thus preventing VN semantic priming). Therefore, we attribute the NV-VN effect to a lexical-syntactic mechanism. The grammatical class of the prime would be the crucial factor in this direction effect: when the prime is a verb, a different kind of processing may activate as compared to when the prime is a noun, predominantly focused on the syntactic – rather than semantic – properties of primes and probes. This would make the semantic relationship between the prime and the probe less relevant, thus hindering the semantic facilitation effect. Hereafter, we will refer to this account as the *grammatical-class-of-the-prime* hypothesis.

Whatever the explanation adopted for the NV-VN asymmetry, the priming effect is crucially influenced here by the grammatical class of the prime, i.e., a piece of information that is stored at the lemma-level. This is particularly relevant for two reasons. First, it is in line with several results obtained on aphasic patients (e.g., Thompson et al., 1997), showing that lexical retrieval of isolated verbs is highly influenced by the number of arguments taken by a verb: the NV-VN asymmetry emerging in the present study provides further evidence that lexical-syntactic information (i.e., lemma-level) is retrieved also in single word paradigms, where subjects could carry out the task without accessing this piece of information; in the present task, for example, information on grammatical class is irrelevant in order to read words aloud and nonetheless it is activated. Second, not only is lexical-syntactic information activated automatically, this also happens very early in printed word processing: as soon as after 100 ms from the prime presentation, its grammatical class influences the lexical processing of the incoming target word.

A possible criticism regarding the cross-class morphological effect observed in this Experiment is that it may also depend on the orthographic and phonological relationship between primes and probes. For example, the presentation of *applauso* as a prime could implicitly pre-activate its initial phoneme(s) in output and this could speed up the reading of the target word *applaudire*. This phonological-orthographic overlap between primes and probes is absent in the semantic condition, where the initial phonemes of primes and probes are different (e.g., *teatro*, theatre, primes *applaudire*, to applaud). Therefore, the phonological-orthographic overlap could explain the facilitation effect in the morphological priming condition *per se* and why this latter is higher than the semantic facilitation.

Indeed, some evidence emerged in this Experiment suggests very little impact of this phonological-orthographic confounding effect. Cascaded models of reading and speech production (e.g., Coltheart, Rastle, Perry, Langdon and Ziegler, 2001; Perry, Ziegler and Zorzi, 2007) suggest that phonemes are activated in the phonological output buffer sequentially from left to right. Since the activation of phoneme nodes also increases over time (until the stimulus disappears), prime words presented for longer should determine higher activation of their initial phonemes as compared to briefly-presented prime words. In other words, if cross-class morphological priming was mostly due to a pre-activation of the initial phonemes in output, then we would expect a larger effect with the longer SOA: however, this is not the case in the present Experiment, where *relatedness* does not interact with *SOA*. In addition, the orthographic overlap between morphologically related primes and probes can hardly be considered as the primary cause of the high morphological facilitation emerged in this Experiment. In fact, orthographic relationship has been proven to inhibit the probe processing at the SOAs used in this study (100 and 300 ms; see Feldman, 2000). In other words, cross-class morphological effects are higher than semantic effects *notwithstanding* the prime-probe orthographic similarity, not *because* of it.

EXPERIMENT 2

To further disentangle the potential phonological-orthographic confounding effects from the genuine morphological effects, we developed a second experiment using control primes that share their initial graphemic and phonemic structure with the targets and the related morphological primes (e.g., *abbazia-abbracciare*, abbey-to hug, will be used as a control for *abbraccio*$_{N}$*-abbracciare*, hug$_{N}$-to hug).

Materials and Methods

Participants

28 right-handed undergraduate students at the University of Milano-Bicocca participated in Experiment 2; none of them had participated in Experiment 1. They were all volunteers, had normal or corrected-to-normal vision, were Italian native speakers and had no history of neurological disorders or learning disabilities. 18 of them were females and 10 were males; their mean age was 22 (range: 20-29).

Materials

Target stimuli were identical to those used in Experiment 1 (45 nouns and 45 verbs). Each of these targets was paired with two different primes: (i) a morphologically related word belonging to a different grammatical class (noun if the target was a verb, and verb if the target was a noun) as in Experiment 1, and (ii) an unrelated word that had the same initial syllable of the morphologically related primes and, consequently, of the target (e.g., *abbazia*, abbey, was chosen as a control for *abbraccio*, embrace$_{N}$, in priming *abbracciare*, to embrace). We decided to match the first syllable instead of just the initial phoneme because we employed SOAs that are longer than those used in previous studies on phonological priming in word naming (e.g., Schiller, 2007). In 13 cases a complete matching of the first syllable was not possible; a control word was thus chosen that matched the first phoneme and the syllable structure. Thanks to the very shallow phoneme-grapheme correspondence in Italian, the phonological prime-control matching also implied an orthographic matching. Furthermore, primes and control words were also matched listwise for frequency and length in letters (word frequency: $t[153.25]=.55$; $p=.65$; length: $t[178]=-1.37$; $p=.17$).

Procedure, data collection, experimental design and statistical analysis

The trial timeline, procedure and apparatus were the same as in Experiment 1. The experimental design was the same except for the fact that only morphological priming effect was tested, since the semantic condition was not influenced by any potential confounding factor in Experiment 1. The variable considered were thus *SOA* (100 ms vs. 300 ms; between-subject), *prime direction* (NV vs.VN; within-subject variable) and *relatedness* (related prime vs. control prime; within-subject variable). Data were trimmed and statistically analyzed as in Experiment 1.

Results

The 99% of the responses were correct and thus accuracy was not analyzed further. The analyses of variance carried out on the mean RTs showed a significant main effect of relatedness (by subjects: $F[1,26]=139.36$; $p<.001$; by items: $F[1,88]=83.90$; $p<.001$) and a significant interaction of relatedness by SOA (by subjects: $F[1,26]=6.08$; $p<.05$; by items: $F[1,88]=5.05$; $p<.05$). Table 4 reports the simple effects of relatedness in the four individual experimental conditions; morphological priming effect emerges as significant irrespective of whether the nouns primed the verbs or vice versa, and irrespective of the SOA used.

In addition, paired-samples t-tests were carried out in order to compare the morphological facilitation emerging in this Experiment with the semantic facilitation obtained in Experiment 1; even when related primes and control words were matched orthographically and phonologically, morphological facilitation is significantly higher than semantic facilitation in three out of four conditions (NV-300: $t[28]=4.69$; $p<.001$; VN-300: $t[28]=3.52$; $p<.005$; NV-100: $t[27]=.52$; $p=.60$; VN-100: $t[27]=4.15$; $p<.001$). As no different morphological effects emerged in the present analysis according to the SOA and the prime direction, the lack of difference between morphological and semantic effects resulting in the NV-100 condition is most likely due to the significant semantic priming emerging in this condition (see Experiment 1).

Discussion

Morphologically related primes and probes do facilitate each other, irrespective of the SOA and of whether nouns prime verbs or, vice versa, verbs prime nouns. The results of Experiment 1 have thus been replicated using control words that shared the initial syllable with the morphologically related primes (i.e., *abbraccio*$_N$-*abbracciare*, hug$_N$-to hug, was compared with *abbazia-abbracciare*, abbey-to embrace); this indicates that cross-class morphological priming was not an artefact due to the pre-activation of the initial(s) phoneme of the target in Experiment 1, but was truly morphological in nature. This result further suggests that morphologically related nouns and verbs share the representation of their root, which is thus represented in a grammatical-class-independent manner. As in the previous Experiment, the symmetry of the effect (*prime direction* does not interact with *relatedness*) reinforces this hypothesis.

Contrary to Experiment 1, morphological facilitation is significantly bigger when the SOA is set to 300 ms than when the SOA is set to 100 ms. This is in line with results on nouns for which morphological priming is stronger as the SOA becomes longer (e.g., Rastle, Davis, Marslen-Wilson, and Tyler 2000). Although significantly smaller than in the 300-ms-SOA conditions, morphological priming is still significant in the two conditions in which the SOA was set to 100 ms, as revealed by simple effect analysis; this confirms the conclusion reached in Experiment 1, i.e., the shared representation of the root is accessed within 100 ms from the presentation of the complex prime word.

Furthermore, cross-class morphological priming is confirmed to be higher than cross-class semantic priming, except for the condition in which nouns primed verbs and the SOA was set to 100 ms; thus, we have further evidence that the morphological effect cannot be traced back just to the semantic relationship implicated by the common root.

EXPERIMENT 3

Experiment 1 has shown that cross-class semantic priming emerges when nouns prime verbs as well as when verbs prime nouns in the 300-ms SOA condition; by contrast, with a 100-ms SOA, facilitation emerges only when nouns prime verbs, but not when verbs prime nouns. This has been tentatively explained in terms of the grammatical class of the prime; when this latter is a verb, lexical-syntactic information is particularly addressed and the semantic relationship between primes and probes becomes less relevant, hindering the semantic facilitation.

In order (i) to better compare cross-class and within-class semantic priming effects and (ii) to further test the effect of the grammatical class of the prime on semantic priming, a further Experiment has been carried out in which noun-noun and verb-verb prime-probe pairs were employed. The same material as in Experiment 1 was used; noun and verb primes were interchanged in order to obtain noun-noun (*bacio-amore*, kiss_N-love_N) and verb-verb (*baciare-amare*, to kiss-to love) pairs from the original verb-noun (*baciare-amore*, to kiss-love_N) and noun-verb (*bacio-amare*, kiss_N-to love) pairs. This design also permit to compare within-class effects obtained with nouns and verbs.

Materials and Methods

Participants

Sixty-four right-handed undergraduate students at the University of Milano-Bicocca participated in Experiment 3; they were all volunteers, had normal or corrected-to-normal vision, were Italian native speakers and had no history of neurological disorders or learning disabilities. None of the subjects also participated in either Experiment 1 or 2. Fifty-two of them were females and 12 were males; their mean age was 23 (range: 19-41).

Materials

The experimental list was composed of 34 target words, 18 verbs and 16 nouns, selected among those used in Experiment 1. Each of these targets was paired with two prime words. First, each target verb/noun was paired with the semantically related word used as prime for its corresponding noun/verb in Experiment 1 (e.g., *applaudire*, to applaud, was paired with *ammirare*, to admire, which was the prime of the nominal counterpart of *applaudire*, *applauso*, in Experiment 1). We used the same material of Experiment 1 in order to keep as constant as possible the strength of the semantic relationship within each prime-target pair; by doing so, any different result could be attributed only to the grammatical class of primes and probes. Then, each target word was paired with a semantically-unrelated word that was matched with the related prime for length and word frequency. Strength of the semantic association was estimated using the same procedure as in Experiment 1: twelve undergraduate students evaluated each prime-probe pair along a 7-point scale. This was made to make sure that related and control pairs were taken from the extreme tails of the semantic association strength distribution (NN: 5.66±.55 vs. 1.76±.63; VV: 5.66±.38 vs. 1.46±.46). Noun and verb targets were matched for word frequency (t[23]=.46; p=.64), word length (t[32]=-.72; p=.48), imageability (t[32]=1.61; p=.12) and age of acquisition (t[32]=-.62; p=.54)

Procedure

The timeline of the trials was identical to that used in Experiment 1 in the 300-ms-SOA condition: a crosshair was displayed on a computer screen for 500 ms, then the prime word was presented in lowercase for 250 ms and was immediately followed by a hash-sign mask lasting 50 ms. The target word appeared in uppercase and the experiment editor application (E-prime 1.1) started the reaction time measurement. Trials were separated by a 1.5-second inter-stimulus interval.

All the remaining aspects of the procedure (e.g., display apparatus and characteristics, instructions, practice trials, data collection procedure) were identical to those employed in Experiment 1.

Experimental design

Two independent variables have been considered in the present Experiment, i.e., the grammatical class of the primes-probes (noun-noun, NN, vs. verb-verb, VV) and the relationship between primes and probes (semantic relationship vs. no relationship). The former was included in the design as a within-subject, between-item variable; by contrast, *relatedness* was used as within-subject, within-item variable.

In order to prevent subjects from being tested with the same target twice, two separate conditions were set, either paired with the related prime or with the unrelated control word; 32 subjects underwent the first condition and 32 performed the second one. Each condition was made up of two blocks; order of presentation was pseudo-randomized within each block (i.e., not more than 3 related or unrelated trials could occur consecutively).

Statistical analysis

Data were preliminarily analysed, trimmed and elaborated for the analyses as in Experiment 1. By-subject and by-item data-sets were analysed through a two-way ANOVA where main effects and interaction were assessed; simple effects were instead calculated through a series of t-tests. In order to better evaluate all these effects, power levels and effect sizes will also be reported.

Results

The percentage of correct responses was at ceiling (99% of all responses were correct) and thus accuracy was not analyzed further. RT analyses reveal a significant main effect of relatedness (by subjects: $F[1,63]=7.83$; $p<.01$; by items: $F[1,32]=5.46$; $p<.05$;). Grammatical class is significant only in the by-subject analysis ($F[1,63]=11.04$; $p<.005$), but not in the by-item analysis ($F[1,32]=.86$; $p=.36$). The interaction between relatedness and grammatical class approached significance in the by-subject analysis ($F[1,63]=3.47$; $p=.07$) and was not significant in the by-item analysis ($F[1,32]=2.07$; $p=.16$). The simple effects of relatedness in NN and VV pairs are reported in Table 5, together with the average RTs in the different conditions. Semantic priming is significant in the NN condition both in the subject ($t=2.59$, $p<.01$) and in the item analysis ($t=3.80$, $p<.001$), whereas there is no facilitation as far as verbs are concerned (by subjects: $t=.87$, $p=.20$; by items: $t=.76$, $p=.23$).

Discussion

Experiment 3 indicates that semantic priming emerges with nouns, but not with verbs. This is a newly reported result, as none of the studies conducted so far on semantic priming in a reading task has investigated the effect of grammatical class (but see Mahon et al., 2007, for evidence in a picture-word interference paradigm); in previous studies only nouns were employed (e.g., Kotz, Cappa, von Cramon and Friederici, 2002) or items from different grammatical classes (mostly nouns, verbs and adjectives) were used together under the implicit assumption that grammatical class was not a relevant factor (e.g,. Tabossi and Laghi, 1992).

It is not easy to account for the fact that semantic priming emerges among nouns, but not among verbs, as there is a number of dimensions along which nouns and verbs differ from a semantic point of view. First, while nouns denote entities (things, persons, animals, abstract concepts), verbs basically predicate about these entities, i.e., either specify their characteristics (as in "birds fly") or describe relationships between them (as in "the cat is chasing the dog"; e.g., Graffi, 1994). Having such different semantic roles, it is not surprising that nouns and verbs may have differently-structured semantic representations causing psychological phenomena that emerge with only one of the two grammatical classes. However, it is not easy to explain why verbs (i.e., words having intrinsically relational concepts) should not in principle elicit semantic priming effects; a reciprocal facilitation is expected as long as some nucleus of meaning is shared between semantic representations, either predicative - as those of verbs - or denotative - as those of nouns. Moreover, only de-verbal nouns were used in this Experiment; therefore, also the semantic representation of nouns was highly relational and thus similar to that of verbs (e.g., *abbraccio*$_N$, hug$_N$, and *abbracciare*, to hug). As a consequence, any noun-verb difference is hardly explainable in the present Experiment in terms of the predicative-referential dichotomy.

In analogy with the proposal firstly made by Warrington and Shallice (1984) to account for disproportionate impairments of natural objects or artifacts, it has been suggested that nouns and verbs may differ in terms of the weighting of sensory and functional information contained in their semantic representations (e.g., Bird, Howard and Franklin, 2000). However, there seems to be no reason to believe that representations based on functional features are less prone to priming effect than concepts based on visual features. Moreover, as discussed above, noun and verb probes included in this Experiment had almost identical semantic representations (e.g., *bacio*$_N$, kiss$_N$, and *baciare*, to kiss); hence, they could hardly have very different weightings of sensory and functional information in their semantic representations

With such a close matching of the *internal* structure of the semantic concepts underlying the nouns and verbs included in the present Experiment, the reason why priming effect emerges with nouns and not with verbs may either (i) refer to the connections *between* different concepts, i.e., to the structural differences between the semantic spaces in which noun- and verb-concepts are embedded (ii) or be non-semantic in nature. We will consider more in depth these hypotheses in the General Discussion.

GENERAL DISCUSSION

Notwithstanding priming effect has been widely used to investigate the structure of the human mental lexicon, the effect of the grammatical class to which primes and probes belong has never been addressed directly. In particular, no previous experiment has assessed cross-class priming effects (i.e., facilitation/inhibition effects obtained when nouns are used as primes and verbs as probes, or vice versa). Nevertheless, these effects may be crucial in clarifying how nouns and verbs are differently represented in the human linguistic system, and may be useful to address more specific issues, e.g., whether morphological roots sub-serving both noun and verb formation are represented in a unitary, grammatical-class independent form. The present study has investigated morphological and semantic cross-class priming effects at different SOAs (100 and 300 ms) in three word naming experiments carried out in Italian; within-class semantic priming has also been tested in Experiment 3 in order to clarify the role of the grammatical class of the prime.

Experiment 1 has shown that (i) cross-class morphological priming (e.g., *applauso-applaudire*, applause-to applaud) emerges at both SOAs, independently from the prime direction (verbs priming nouns vs. nouns priming verbs), (ii) this effect is consistently larger than cross-class semantic priming (e.g., *teatro-applaudire*, theatre-to applaud), and (iii) cross-class semantic priming is independent from prime direction when the SOA is set to 300 ms, whereas it only emerges when nouns prime verbs in the 100-ms SOA condition (see Table 6). Experiment 2 confirmed the results obtained in Experiment 1 and showed that cross-class morphological effects do not depend on the prime-probe orthographic/phonological overlap (e.g., *applauso-applaudire* was compared to *appetito-applaudire,* appetite-to applaud). Finally, Experiment 3 has provided evidence that also within-class semantic priming is sensitive to grammatical class, i.e., it emerges only among nouns (e.g., *teatro-applauso*, theatre-applause) and not among verbs (*ammirare-applaudire*, to admire-to applaud). This pattern of results is revealing about both the morphological and the semantic representation of nouns and verbs in the human linguistic system.

Morphology and grammatical class in the brain

The results obtained in the present study support the theoretical claim that morphological roots have independent representation in the human linguistic system and, at least at some level of processing, this representation is not marked for grammatical class (Deutsch et al., 1998). The first part of the claim, i.e., roots have independent representation, was firstly suggested – at least implicitly - many years ago (Taft and Forster, 1975); this hypothesis has received definitive evidence by the morphological effects reported also with non-words (e.g., Taft and Forster, 1975; Deutsch et al., 1998) and by the demonstration that morphological effects are not explainable just in terms of overlap in meaning and orthography (e.g., Feldman, 2000). The present study shows that words sharing a same root facilitate each other also when they belong to different grammatical classes (nouns and verbs); this clearly demonstrates that the representation of the common root is unmarked for grammatical class, i.e., both noun and verb processing makes use of the same root representation and, thus, nouns and verbs prime the processing of morphologically-related words belonging to the opposite grammatical class. If two separate representations of the same root existed, one for the nominal root and one for the verbal root, no facilitation would in fact be expected; rather, some interference should arise, as the two lexical representations would compete for selection (e.g., Laudanna et al., 1989).

A second relevant aspect of the results emerged in the present study is that cross-class morphological effect arises when the SOA is as brief as 100 ms; this reveals that the grammatical-class-independent representation of roots is accessed quite early in written word processing. Very early morphological priming effects have already been reported by Rastle et al. (2000) in lexical decision at brief SOAs (43 ms), independently from the semantic transparency of the prime-probe relationship (*departure-depart* determines the same priming effect as *apartment-apart*); this lead the authors to suggest the existence of a structural segmentation process that operates in the early stages of visual word processing and plays a role in allowing later stages of lexical processing to capitalize upon regularities between form and meaning (see Rastle and Davis, 2003). We believe that cross-class morphological priming arises at this level of processing: the common root underlying verbs and their corresponding nouns would be accessed at this early orthographic-morphological stage. The absence of any grammatical class representation would be perfectly expected at this level, as this appears to be purely orthographically grounded, i.e., not influenced by semantic transparency (as revealed by Rastle et al., 2000) and grammatical class (as revealed by the present study). Of course, this interpretation gives rise to the prediction that cross-class morphological priming should also be observed at briefer SOAs than those employed in the present study (comparable to those used by Rastle et al., 2000); further evidence is needed to give additional support to this interpretation.

Semantics and grammatical class in the brain

A few studies have investigated the relationship between semantic effects and grammatical class. Recently, Mahon and colleagues (2007) have shown that grammatical class effect emerges in a picture-word interference paradigm. In fact, the effect of semantically related words written over object pictures to be named depends on grammatical class: semantically related verbs facilitate noun retrieval, which is instead slowed down by semantically related nouns. As reported in the Introduction, the authors interpreted this result by arguing that, as the task requires to name objects, written verbs do not compete with the target noun for selection and thus no interference effects emerge. In the present study a reading task was used; hence, no criterion was set on the grammatical class of the response. As a consequence, no grammatical class effect can be explained in terms of task-related constraints (for further evidence on task-dependent grammatical class effects, see Chapter 4).

As opposed to morphological effects, the semantic effects strongly depend on the SOA and the grammatical class of primes and probes (Experiment 1 and 3). When the presentation of the prime preceded the onset of the target by 100 ms, facilitation only emerged for nouns priming verbs, and not for verbs priming nouns. There is no clear account for this asymmetry within the lexical system; if two lexical-semantic nodes are related to each other, it is hard to imagine how activation could spread in one direction (i.e., from noun nodes to semantically-related verb nodes), but not in the opposite direction (from verb nodes to semantically-related noun nodes). Therefore, we attributed this direction effect to a lexical-syntactic mechanism (the *grammatical-class-of-the-prime* hypothesis). Indeed, we suggest that the presentation of a verb as a prime triggers a completely different processing of the stimulus according to which lexical-syntactic (i.e., lemma level) characteristics – and not semantic features – are mostly activated; this would make the semantic relationship between primes and probes poorly relevant and would determine the absence of semantic priming effects. Though legitimate, this hypothesis is not completely supported by the pattern of semantic facilitation emerging with the 300-ms SOA (see Table 6): in this latter condition, in fact, we did not obtain semantic priming in VV trials – as we should expect, the prime being a verb –, but we did observe semantic priming in VN trials, where the prime is again a verb and thus no facilitation should emerge. We can thus conclude that our explanation of the lack of semantic priming in the 100-ms-SOA VN condition cannot be generalized to the case in which the SOA was set to 300 ms. As a final remark, the *grammatical-class-of-the-prime* hypothesis implies that a purely lexical-syntactic information (the grammatical class of the prime) becomes available within 100 ms from the presentation of written words; this suggests a very fast access (perhaps just implicit) to the information stored at the lemma level.

We have seen that the *grammatical-class-of-the-prime* hypothesis does not hold with a 300-ms SOA; how could we thus explain the pattern of semantic priming obtained with such an SOA? We have shown that cross-class semantic priming does not depend from prime direction; no matter whether a noun primes a verb or vice versa, semantically related nouns and verbs do prime each other. By contrast, no facilitation emerged when both the prime and the probe were verbs. The possibility that this may be due to the internal structure of verb-related semantic concepts, i.e., their basically predicative structure and/or their mostly functional-feature-based representation, has been discussed in Experiment 3. However, this hypothesis is rather unlikely as nouns and verbs used in the present study were closely matched for their semantic representation (nouns were all de-verbal, e.g., *abbraccio*$_N$, hug$_N$).

It appears to be more likely that the absence of semantic priming between verbs is due to the general structure of the semantic space framing verb-concepts. One may argue, for example, that semantic representations underlying verbs are less interconnected to each other as they tend to share fewer semantic features than nouns; verb-concepts would thus form an emptier semantic space in which spreading of activation among nodes is scarce (see McRea, de Sa and Seidenberg, 1997 and Humphreys, Riddoch and Quinlan, 1988 for related proposals). Indeed, it is not difficult to explain in feature terms why "tuna" and "shark" are semantically related: they both live in the sea, they swim, they have gills, they are about 2-meters long, and they have fins. This wide range of shared features defines a super-ordinate concept to which both "tuna" and "shark" belong ("fish"), thus creating also hierarchical relationships. It is undoubtedly more difficult to find common features between semantically related verbs like "run" and "walk" (even if they both refer to movement, they have to do with legs, they allow people to move). This poorer sharing of features is arguably what makes verbs having a weaker within-level structure (i.e., few coordinate verb-concepts that may be considered as related to each other, like with "shark" and "tuna") and across-level structure (i.e., few super-ordinate verb-concepts entertaining with lower-level verbs a relationship which is similar to that holding between "fish" and "shark") as compared to nouns. Indeed, one could hardly think about more than two or three semantic categories of verbs (e.g., movement verbs, psychological verbs and very few others), each of which includes relatively few items; by contrast, one may find several different semantic categories of nouns (e.g., animate objects, abstract objects, tools, musical instruments, vegetables, and many others), each of which generally includes a great number of items. We suggest that this is why semantic priming emerges easily with nouns, but much less readily with verbs. Of course, this argument holds under the assumption that the semantic space is feature-based. This is actually a basic assumption of most of the psychological semantic theories suggested so far (e.g., Farah and McClelland, 1991, Warrington and Shallice, 1994), but seems to have a rather weak theoretical linguistic motivation when nouns and verbs are considered jointly.

CONCLUSION

In the present study we have investigated how the grammatical class of the prime and the probe influences morphological and semantic priming effects; this has been done by assessing cross-class morphological priming and cross- and within-class semantic priming at different SOAs.

Results show that morphologically related nouns and verbs facilitate each other (i) irrespectively of whether the noun primes the verb or vice versa, (ii) at both the SOAs investigated and (iii) independently from any possible semantic, orthographic and phonological concurrent effect. This pattern of results drove us to hypothesize the existence of a level of representation at which morphological roots are represented free from any grammatical class information: as a consequence, the same root node, e.g., *baci-*, would be addressed in recognizing both *bacio*$_N$, kiss$_N$, and *baciare*, to kiss. Given that cross-class morphological effects emerge also at the shorter SOA (100 ms), and in line with the suggestion made by Rastle and Davis (2003), we place this level of representation very early in the written word recognition process; this stage would be addressed before a complete lexical access is reached (i.e., before accessing the orthographic input lexicon). Being so peripheral, it is not surprising that this level of representation is not influenced by semantic transparency ('apartment' facilitates 'apart' exactly as 'departure' facilitates 'depart'; see Rastle et al., 2000) and grammatical class (as shown in the present experiment).

The results are somewhat more intricate as far as semantic priming is concerned; this has been shown to emerge across grammatical classes at 300-ms SOA, but only when nouns prime verbs – and not vice versa – when the SOA is set to 100 ms. Even more surprisingly, no semantic priming has emerged in the 300-ms-SOA condition when verbs were used both as primes and as probes (e.g., *applaudire-ammirare*, to applaud-to admire). Given the complete matching of nouns and verbs for frequency, length, imageability, age of acquisition and internal structure of the underlying semantic representation, the lack of semantic priming between verbs may only be interpreted as (i) a consequence of the emptier semantic space framing verbal concepts (see McRea, de Sa and Seidenberg, 1997) or (ii) as a syntactic effect driven by the grammatical class of the prime *per se*, which determines a high activation of the syntactic features of words and makes the semantic relationship between prime and probe poorly relevant. Nevertheless, this latter explanation (*the grammatical-class-of-the-prime* hypothesis) seems to hold only when the prime appears 100 ms before the target, but not with the longer SOA (300 ms).

Tables

Table 1. Lexical-semantic variables for nouns and verbs in the 45 pairs used as stimuli in Experiment 1 (mean ± standard deviation).

Variable	Verbs (n=45)	Nouns (n=45)	t Test	p
Oral stem frequency	36.53 ± 77.66	11.02 ± 15.28	2.16	*<.05*
Oral word surface frequency	8.24 ± 10.84	8.10 ± 16.23	.48	n.s.
Number of letters	8.06 ± 1.54	7.71 ± 2.41	.24	n.s.
Number of syllables	3.47 ± 0.59	3.09 ± 0.97	2.23	*<.05*
Age of acquisition	4.18 ± 1.43	3.77 ± 1.31	-1.42	n.s.
Imageability	4.52 ± 0.68	4.30 ± 0.92	1.28	n.s.

Table 2. Example of prime-target pair for each condition included in Experiment 1.

	Morphological				Semantic			
	Related		Unrelated		Related		Unrelated	
	Prime	Target	Prime	Target	Prime	Target	Prime	Target
NV	*bacio* $kiss_N$	*baciare* to kiss	*svago* amusement	*baciare* to kiss	*amore* $love_N$	*baciare* to kiss	*popolo* folk	*baciare* to kiss
VN	*baciare* to kiss	*bacio* $kiss_N$	*giovare* to promote	*bacio* $kiss_N$	*amare* to love	*bacio* $kiss_N$	*curare* to cure	*bacio* $kiss_N$

Table 3. Experiment 1. Simple effects of relatedness in the by-subject and by-item data-sets. Mean Rts, t-vlaues, probability levels and effect sizes are reported. NV 300, nouns prime verbs with an SOA of 300 ms; VN 300, verbs prime nouns with an SOA of 300 ms; NV 100, nouns prime verbs with an SOA of 100 ms; VN 100, verbs prime nouns with an SOA of 100 ms.

		Morphological priming				Semantic priming			
		NV 300	VN 300	NV 100	VN 100	NV 300	VN 300	NV 100	VN 100
By subjects	Unrelated	538	527	567	551	497	500	513	503
	Related	492	492	536	516	490	491	497	505
	Facilitation	46	35	31	35	7	9	16	-2
	t-value	7.12	6.90	4.48	5.81	1.92	2.15	2.93	.58
	p	<.001	<.001	<.001	<.001	<.05	.01	<.01	.71
	Effect size (d)	1.75	1.16	.74	.97	.31	.27	.48	.08
By item	Unrelated	537	526	567	551	497	498	507	502
	Related	491	492	536	517	490	491	493	498
	Facilitation	46	34	31	34	7	7	14	4
	t-value	10.42	4.96	5.32	7.44	1.68	1.40	2.42	.88
	p	<.001	<.001	<.001	<.001	.06	.09	.01	.80
	Effect size (d)	.55	.41	.47	.64	.16	.17	.23	.08

Table 4. Experiment 2. Simple effects of relatedness in the by-subject and by-item data-sets. Mean Rts, t-vlaues, probability levels and effect sizes are reported. NV 300, nouns prime verbs with an SOA of 300 ms; VN 300, verbs prime nouns with an SOA of 300 ms; NV 100, nouns prime verbs with an SOA of 100 ms; VN 100, verbs prime nouns with an SOA of 100 ms.

		Morphological priming			
		NV 300	VN 300	NV 100	VN 100
By subjects	Unrelated	539	535	493	492
	Related	506	506	476	468
	Facilitation	33	29	17	24
	t-value	9.57	10.49	3.88	5.60
	P	<.001	<.001	<.005	<.001
	Effect size (d)	3.47	3.21	1.41	2.31
By item	Unrelated	539	536	496	493
	Related	506	506	476	469
	Facilitation	33	30	20	24
	t-value	6.52	6.04	3.74	4.32
	p	<.001	<.001	.001	<.001
	Effect size (d)	1.24	1.17	.79	.80

Table 5. Experiment 3. Simple effects of relatedness in the by-subject and by-item data-sets. Mean Rts, t-vlaues, probability levels and effect sizes are reported. N, nouns prime nouns; V, verbs prime verbs.

		N	V
By subjects	Unrelated	527	511
	Related	514	508
	Facilitation	13	3
	t-value	2.59	.87
	p	.01	.20
	Effect size (d)	.36	.14
By item	Unrelated	528	512
	Related	513	508
	Facilitation	15	4
	t-value	3.80	.76
	p	<.001	.23
	Effect size (d)	.23	.06

Table 6. Sum up of the results obtained in Experiments 1, 2 and 3: the table reports whether the effects indicated in the leftmost column is present (+) or not (–) in the conditions specified by the two uppermost rows. NN, nouns priming nouns, NV, nouns priming verbs, VN, verbs priming nouns, VV, verbs priming verbs, n.t., the effect has not been tested.

	SOA=300 ms				SOA=100 ms	
	NN	NV	VN	VV	NV	VN
Morphological priming	n.t.	+	+	n.t.	+	+
Semantic priming	+	+	+	–	+	–
Morphological>semantic	n.t.	+	+	n.t.	+	+

APPENDIX A: LIST OF THE STIMULI USED IN EXPERIMENT 1

GC = grammatical class; NV = nouns priming verbs; VN = verbs priming nouns; Morph rel = morphologically related; Morph cnt = word used as control for the morphologically related prime; Sem rel = semantically related; Sem cnt = word used as control for the semantically related prime.

N	GC	Probe	Morph rel prime	Morph cnt prime	Sem rel prime	Sem cnt prime
1	NV	abbracciare	abbraccio	drappello	bacio	svago
2	NV	arrestare	arresto	profilo	manette	casello
3	NV	baciare	bacio	svago	amore	popolo
4	NV	ballare	ballo	multa	canto	mappa
5	NV	calcolare	calcolo	missile	numero	persona
6	NV	cantare	canto	suolo	ballo	multa
7	NV	crollare	crollo	nebbia	edificio	panorama
8	NV	lanciare	lancio	stadio	palla	duomo
9	NV	massaggiare	massaggio	discordia	olio	sole
10	NV	saltare	salto	furto	ostacolo	indirizzo
11	NV	salutare	saluto	dogana	incontro	modello
12	NV	sbadigliare	sbadiglio	crespella	sonno	forno
13	NV	scoppiare	scoppio	broglio	ordigno	casello
14	NV	soffiare	soffio	milza	aria	data
15	NV	sparare	sparo	fieno	pistola	colonia
16	NV	starnutire	starnuto	trespolo	fazzoletto	tartaruga
17	NV	volare	volo	data	uccello	barile
18	NV	bombardare	bombardamento	diplomazia	missile	formula
19	NV	camminare	camminata	mozzarella	passo	borsa
20	NV	conversare	conversazione	protocollo	parola	potere
21	NV	costruire	costruzione	democrazia	casa	vita
22	NV	esplodere	esplosione	accademia	bomba	turno
23	NV	evadere	evasione	capitano	ladro	mutuo
24	NV	giurare	giuramento	incursione	processo	effetto
25	NV	interrogare	interrogazione	enciclopedia	maestro	sezione
26	NV	leggere	lettura	autunno	libro	costo
27	NV	nascere	nascita	criterio	bambino	vertice
28	NV	partire	partenza	campione	viaggio	stampa
29	NV	pattinare	pattinaggio	mozzarella	ghiaccio	schiera
30	NV	piovere	pioggia	dramma	ombrello	carisma

N	GC	Probe	Morph rel prime	Morph cnt prime	Sem rel prime	Sem cnt prime
31	NV	potare	potatura	fusibile	albero	ettaro
32	NV	pregare	preghiera	quattrino	chiesa	cambio
33	NV	radere	rasatura	papavero	barba	freno
34	NV	ridere	risata	laguna	allegria	cammello
35	NV	ruggire	ruggito	crinale	leone	catena
36	NV	salvare	salvataggio	accessorio	miracolo	verifica
37	NV	scrivere	scrittura	concerto	matita	cupola
38	NV	ululare	ululato	obitorio	lupo	dote
39	NV	applaudire	applauso	edicola	teatro	totale
40	NV	cadere	caduta	legame	gradino	assenso
41	NV	correre	corsa	sorta	gara	filo
42	NV	mordere	morso	felpa	cane	tubo
43	NV	piangere	pianto	scalpo	lacrima	tributo
44	NV	raccogliere	raccolta	ingresso	frutta	maglia
45	NV	nevicare	Neve	dose	montagna	sostegno
46	VN	abbraccio	abbracciare	sconvolgere	stringere	spostare
47	VN	applauso	applaudire	adoperare	ammirare	abbinare
48	VN	arresto	arrestare	collocare	rubare	dormire
49	VN	bacio	baciare	giovare	amare	curare
50	VN	ballo	ballare	mediare	cantare	versare
51	VN	bombardamento	bombardare	sfrigolare	distruggere	proteggere
52	VN	caduta	cadere	basare	scivolare	implicare
53	VN	calcolo	calcolare	ascoltare	sommare	premere
54	VN	camminata	camminare	inventare	correre	citare
55	VN	canto	cantare	fermare	suonare	rompere
56	VN	conversazione	conversare	disprezzare	parlare	seguire
57	VN	corsa	correre	lottare	camminare	convocare
58	VN	costruzione	costruire	accettare	distruggere	proteggere
59	VN	crollo	crollare	spargere	cadere	curare
60	VN	esplosione	esplodere	dipingere	distruggere	proteggere
61	VN	evasione	evadere	affinare	scappare	spedire
62	VN	giuramento	giurare	fingere	promettere	sorprendere
63	VN	interrogazione	interrogare	moltiplicare	studiare	giungere
64	VN	lancio	lanciare	gestire	prendere	trattare
65	VN	lettura	leggere	vendere	scrivere	spiegare
66	VN	massaggio	massaggiare	strangolare	rilassare	rammentare

N	GC	Probe	Morph rel prime	Morph cnt prime	Sem rel prime	Sem cnt prime
67	VN	morso	mordere	narrare	mangiare	marciare
68	VN	nascita	nascere	perdere	morire	subire
69	VN	Neve	nevicare	immolare	piovere	destare
70	VN	partenza	partire	rendere	arrivare	rimanere
71	VN	pattinaggio	pattinare	mendicare	scivolare	implicare
72	VN	pianto	piangere	mangiare	ridere	varare
73	VN	pioggia	piovere	destare	nevicare	immolare
74	VN	potatura	potare	chinare	tagliare	suonare
75	VN	preghiera	pregare	stupire	adorare	obbedire
76	VN	raccolta	raccogliere	affrontare	buttare	dormire
77	VN	rasatura	radere	munire	tagliare	cacciare
78	VN	risata	ridere	varare	piangere	marciare
79	VN	ruggito	ruggire	fremere	sbranare	strigliare
80	VN	salto	saltare	versare	superare	ricevere
81	VN	saluto	salutare	recitare	partire	cercare
82	VN	salvataggio	salvare	godere	morire	toccare
83	VN	sbadiglio	sbadigliare	strimpellare	dormire	buttare
84	VN	scoppio	scoppiare	tracciare	bruciare	pregare
85	VN	scrittura	scrivere	chiamare	leggere	vendere
86	VN	soffio	soffiare	guastare	sbuffare	stridere
87	VN	sparo	sparare	vietare	colpire	firmare
88	VN	starnuto	starnutire	tramortire	tossire	vibrare
89	VN	ululato	ululare	erodere	abbaiare	dirimire
90	VN	volo	volare	recare	decollare	oscillare

APPENDIX B: LIST OF THE STIMULI USED IN EXPERIMENT 2

GC = grammatical class; NV = nouns priming verbs; VN = verbs priming nouns; Morph rel = morphologically related; Morph cnt = word used as control for the morphologically related prime.

N	GC	Probe	Morph rel prime	Morph cnt prime
1	NV	abbracciare	abbraccio	abbazia
2	NV	arrestare	arresto	arredo
3	NV	baciare	bacio	bagno
4	NV	ballare	ballo	balzo
5	NV	calcolare	calcolo	calma
6	NV	cantare	canto	campo
7	NV	crollare	crollo	cronaca
8	NV	lanciare	lancio	lanterna
9	NV	massaggiare	massaggio	massiccio
10	NV	saltare	salto	saldo
11	NV	salutare	saluto	sabato
12	NV	sbadigliare	sbadiglio	sbarra
13	NV	scoppiare	scoppio	scoperta
14	NV	soffiare	soffio	soffitto
15	NV	sparare	sparo	spada
16	NV	starnutire	starnuto	statua
17	NV	volare	volo	voce
18	NV	bombardare	bombardamento	bordo
19	NV	camminare	camminata	cammello
20	NV	conversare	conversazione	concerto
21	NV	costruire	costruzione	costume
22	NV	esplodere	esplosione	esperienza
23	NV	evadere	evasione	etichetta
24	NV	giurare	giuramento	giugno
25	NV	interrogare	interrogazione	indirizzo
26	NV	leggere	lettura	lenzuolo
27	NV	nascere	nascita	natura
28	NV	partire	partenza	parlamento
29	NV	pattinare	pattinaggio	pattuglia
30	NV	piovere	pioggia	piombo
31	NV	potare	potatura	popolo
32	NV	pregare	preghiera	presidio

N	GC	Probe	Morph rel prime	Morph cnt prime
33	NV	radere	rasatura	rapina
34	NV	ridere	risata	riparo
35	NV	ruggire	ruggito	rossetto
36	NV	salvare	salvataggio	salmone
37	NV	scrivere	scrittura	straccio
38	NV	ululare	ululato	universo
39	NV	applaudire	applauso	appetito
40	NV	cadere	caduta	carota
41	NV	correre	corsa	corda
42	NV	mordere	morso	morbo
43	NV	piangere	pianto	pianta
44	NV	raccogliere	raccolta	raccordo
45	NV	nevicare	neve	nido
46	VN	abbraccio	abbracciare	abbondare
47	VN	applauso	applaudire	appendere
48	VN	arresto	arrestare	arredare
49	VN	bacio	baciare	bagnare
50	VN	ballo	ballare	balzare
51	VN	bombardamento	bombardare	bollire
52	VN	caduta	cadere	capire
53	VN	calcolo	calcolare	calmare
54	VN	camminata	camminare	cambiare
55	VN	canto	cantare	cancellare
56	VN	conversazione	conversare	convertire
57	VN	corsa	correre	corrispondere
58	VN	costruzione	costruire	costringere
59	VN	crollo	crollare	criticare
60	VN	esplosione	esplodere	esclamare
61	VN	evasione	evadere	evolvere
62	VN	giuramento	giurare	giustificare
63	VN	interrogazione	interrogare	installare
64	VN	lancio	lanciare	lottare
65	VN	lettura	leggere	legare
66	VN	massaggio	massaggiare	massacrare
67	VN	morso	mordere	mormorare
68	VN	nascita	nascere	nascondere
69	VN	neve	nevicare	negare

N	GC	Probe	Morph rel prime	Morph cnt prime
70	VN	partenza	partire	parlare
71	VN	pattinaggio	pattinare	pendere
72	VN	pianto	piangere	piantare
73	VN	pioggia	piovere	piegare
74	VN	potatura	potare	posare
75	VN	preghiera	pregare	premere
76	VN	raccolta	raccogliere	raccontare
77	VN	rasatura	radere	ragionare
78	VN	risata	ridere	rifiutare
79	VN	ruggito	ruggire	russare
80	VN	salto	saltare	saldare
81	VN	saluto	salutare	sapere
82	VN	salvataggio	salvare	sancire
83	VN	sbadiglio	sbadigliare	sbagliare
84	VN	scoppio	scoppiare	scoprire
85	VN	scrittura	scrivere	scuotere
86	VN	soffio	soffiare	soffrire
87	VN	sparo	sparare	sparire
88	VN	starnuto	starnutire	stancare
89	VN	ululato	ululare	unire
90	VN	volo	volare	votare

APPENDIX C: LIST OF THE STIMULI USED IN EXPERIMENT 3

GC = grammatical class; NN = nouns priming nouns; VV = verbs priming verbs; Sem rel = semantically related; Sem cnt = word used as control for the semantically related prime.

N	GC	Probe	Sem rel prime	Sem cnt prime
1	VV	nascere	morire	subire
2	VV	giurare	promettere	sorprendere
3	VV	ruggire	sbranare	strigliare
4	VV	salutare	partire	cercare
5	VV	ridere	piangere	marciare
6	VV	pregare	adorare	obbedire
7	VV	pattinare	scivolare	implicare
8	VV	abbracciare	stringere	spostare
9	VV	applaudire	ammirare	abbinare
10	VV	conversare	parlare	seguire
11	VV	interrogare	studiare	giungere
12	VV	volare	decollare	oscillare
13	VV	baciare	amare	basare
14	VV	ululare	abbaiare	dirimere
15	VV	massaggiare	rilassare	rammentare
16	VV	soffiare	sbuffare	stridere
17	VV	camminare	correre	citare
18	VV	ballare	cantare	versare
19	NN	camminata	passo	borsa
20	NN	potatura	albero	ettaro
21	NN	rasatura	barba	freno
22	NN	interrogazione	maestro	sezione
23	NN	preghiera	chiesa	cambio
24	NN	evasione	ladro	mutuo
25	NN	risata	allegria	cammello
26	NN	partenza	viaggio	stampa
27	NN	pattinaggio	ghiaccio	schiera
28	NN	nascita	bambino	vertice
29	NN	lettura	libro	costo
30	NN	bombardamento	missile	formula
31	NN	esplosione	bomba	turno
32	NN	neve	montagna	sostegno
33	NN	giuramento	processo	effetto
34	NN	starnuto	fazzoletto	tartaruga

4 NOUNS AND VERBS IN THE BRAIN: GRAMMATICAL CLASS AND TASK SPECIFIC EFFECTS AS REVEALED BY fMRI[1]

INTRODUCTION

Since the mid 1980s, literature has concentrated on aphasic patients suffering from lexical retrieval difficulties predominantly affecting either nouns or verbs (e.g. Miceli, Silveri, Villa, & Caramazza, 1984; McCarthy & Warrington, 1985; Thompson, Shapiro, Li & Schendel, 1994). Moreover, theoretical linguists describe nouns and verbs as being different lexical entities; indeed, they are affected by different syntactic phenomena (e.g. noun phrase movement vs. verb movement), have different morphological properties and different lexical and lexical-semantic representations (see for example Dowty, 1989; Levelt, Roelofs, & Meyer 1999). Therefore the hypothesis that nouns and verbs have separate and diverse representation in the human mind and that cerebral brain damage may affect one while sparing the other appears to have a strong theoretical base.

In the last 20 years there has been a body of neuropsychological evidence supporting the view that nouns and verbs are differently represented in the cognitive system (e.g. Berndt, Mitchum, Haendiges, & Sandson, 1997; Luzzatti, Raggi, Zonca, Pistarini, Contardi, & Pinna, 2002; Aggujaro, Crepaldi, Pistarini, Taricco, & Luzzatti, 2006; Crepaldi, Aggujaro, Arduino, Zonca, Ghirardi, Inzaghi, Colombo, Chierchia, & Luzzatti, 2006). The noun-verb dissociations observed in aphasic patients have been explained in several different ways.

[1] The present study has been carried out in collaboration with Manuela Berlingeri and Eraldo Paulesu (Department of Psychology, University of Milano-Bicocca). I also thank Rossella Roberti for her assistance in the data analysis and Giuseppe Scialfa (Department of Neuroradiology, Niguarda-Cà Granda Hospital,

According to Caramazza and colleagues (e.g., Rapp & Caramazza, 2002), dissociated impairments may be caused by damage which selectively affects verbs or nouns at a late lexical stage (phonological or orthographical output lexicons); this is suggested by the fact that the patients participating in the study performed better on verbs in spoken production, and on nouns in written comprehension. Other researchers (e.g., Berndt, Mitchum, Haendiges & Sandson, 1997) have claimed the existence of a lexical-syntactic representation of grammatical class at a more central lexical level (the *lemma*, see Levelt, Roelofs and Meier, 1999). Bird, Howard & Franklin (2000), on the other hand, argued that noun-verb dissociation might be a semantic, rather than lexical, phenomenon; moreover, they suggested that many dissociations might be generated by an increased level of sensibility to imageability in aphasic patients. Finally, selective verb deficits have been explained as a consequence of syntactic damage (e.g., Friedmann, 2000) resulting from a pathological pruning of the syntactic tree which would prevent verbs from moving to the relevant functional categories and being inflected.

As the functional difference between the two grammatical classes received further substantiation, more and more attention was dedicated to the question of whether different neural circuits are responsible for noun and verb processing. In recent years many studies have tried to identify the brain areas underlying noun and verb processing using Positron Emission Tomography (PET; e.g. Warburton, Wise, Price, Weiller, Hadar, Ramsay, & Frackowiak, 1996), functional Magnetic Resonance Imaging (fMRI; e.g. Tyler, Bright, Fletcher, & Stamatakis, 2004), Magnetoencephalography (MEG; e.g. Sörös, Cornelissen, Laine, & Salmelin, 2003), Transcranic Magnetic Stimulation (TMS; e.g. Cappa, Sandrini, Rossini, Sosta, & Miniussi, 2002) and anatomo-clinical correlations (e.g. Aggujaro et al.,

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Milano) who made us available the fMRI apparatus.

2006). However, the results of these studies do not seem to converge on a well-established pattern of cerebral areas (see Table 1 and Figure 1).

The lack of consistency in the functional imaging literature could be due to the wide variety of experimental and control conditions used; in fact, the cerebral basis of the lexical representation of nouns and verbs has been investigated through several tasks such as lexical decision, picture naming, semantic decision or fluency; it must also be said that a careful analysis of the cognitive levels called upon by the experimental task-baseline comparison has not always been carried out. In addition, the data obtained so far may well be influenced by the different statistical methods used and by the different sample sizes (see Table 1).

A further issue in the neuroimaging literature on nouns and verbs concerns lexical-semantic variables (e.g., frequency, imageability, stimulus complexity). These variables have been found to be very important in predicting both the performance of aphasic patients (e.g. Nickels & Howard, 1995) and the RTs of normal speakers on naming tasks (e.g. Bates, Burani, D'Amico, & Barca, 2001). In particular, imageability is a very important lexical-semantic variable; not only does it have a strong influence on performance in lexical retrieval tasks, it also correlates with grammatical class. Indeed, there is a well-known constraint in picture naming tasks (PNT), whereby verbs usually have lower imageability than concrete nouns and pictures of nouns with comparable imageability would not elicit an unambiguous target word.

Nonetheless, imageability has received very little attention in neuroimaging studies, particularly in those focusing on noun and verb processing; only, two studies have considered imageability when investigating the brain areas underlying noun and verb processing.

Tyler, Russell, Fadili and Moss (2001) included imageability in their experimental design (Experiment 1) and matched nouns and verbs for this variable (Experiment 2). A lexical decision task (Exp 1) did not show any brain area that is sensitive to either grammatical class or imageability. This lack of imageability and grammatical class effect is at odds with the crucial role attributed to imageability by several neuropsychological studies (e.g., Bird et al., 2000, Luzzatti et al., 2002) and also with the neuroimaging evidence provided by Wise et al. (2000) showing an activation modulated by imageability in the left mid-fusiform gyrus, the inferior temporal gyrus and the left mid-superior temporal gyrus. Experiment 2, in which a semantic categorization task was used, gave very similar results, with no area emerging as specific for either nouns or verbs. Tyler and colleagues (2001) explain these results by suggesting that grammatical class effects arise only in tasks that require the use of grammatical class information for the purposes of morphological processing.

In the other study in which imageability was controlled (Bedny and Thompson-Schill, 2006), the authors compared a semantic decision task on written stimuli to passive viewing of a crosshair and found a significant grammatical-class-by-imageability interaction in the left inferior frontal gyrus and in the left middle temporal gyrus; these areas would respond more to verbs than nouns when stimuli are highly imageable, and more to nouns than verbs when stimuli are poorly imageable. The authors argued that this interaction could be explained by the number of meanings underlying a word; the more they are, the higher the activation of the left inferior frontal gyrus. As the number of meanings correlates positively with the imageability of verbs, but negatively with the imageability of nouns, this hypothesis would satisfactorily explain the grammatical-class-by-imageability interaction. Therefore, the left inferior frontal gyrus might not be specific for grammatical class, but could come into play in the case of competition between alternatives during lexical access, resulting in a higher processing load (see Thompson-Schill et al., 1997).

Moreover, stimulus complexity and task difficulty (which influence resource demand) are two important factors to be considered in imaging studies of nouns and verbs; these factors may vary according to grammatical class. Take picture naming, for instance. While an object is represented with a single pictorial unit, the pictorial representation of verbs is much less direct, since it is impossible to actually draw actions. A picture eliciting a verb represents an agent performing an action in a specific context, often with a theme and a goal. Therefore, compared to nouns, the retrieval of a verb arguably requires extra-cognitive steps that may well be more onerous in terms of cognitive resources.

It is worth noting that not only are neuroimaging data on nouns and verbs from different studies barely consistent with each other, they are also quite at odds with those obtained from anatomo-clinical correlation studies on noun-verb dissociation in aphasia. In fact, previous studies have indicated predominant temporal damage for noun impairment (e.g. Damasio & Tranel, 1993; Hillis, Tuffiash, Wityk, & Barker, 2002), whereas neuroimaging evidence has also shown left premotor/prefrontal activation in noun processing, particularly when semantic tasks were used (e.g., Tyler, Stamatakis, Dick, Bright, Fletcher, & Moss, 2003). The picture is even more intricate for verbs. In fact, lesion studies on verb-impaired aphasic patients frequently describe large lesions involving the left frontal cortex (see Daniele, Giustolisi, Silveri, Colosimo, & Gainotti, 1994; Shapiro & Caramazza, 2003), but there are several reports of verb-impaired patients whose lesions lie outside the left frontal regions (Daniele et al., 1994; Silveri & Di Betta, 1997; Silveri, Perri, & Cappa, 2003) and, more importantly, involve more posterior, temporo-parietal areas (e.g., Aggujaro et al., 2006). Furthermore, as reported in Figure 1, results from neuroimaging studies are also controversial, in some cases supporting left frontal involvement (Shapiro, Mottaghy, Schiller, Poeppel, Fluss, Muller, Caramazza, & Krause, 2005), in others a major role of the left parietal areas (Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995) or crucial involvement of the inferior temporal regions (Tranel, Martin, Damasio, Grabowski, & Hichwa, 2005); finally, there are studies that suggest a same network sub-serving nouns and verbs (Tyler, Russell, Fadili, & Moss, 2001) or a similar network, but with verbs yielding stronger activation (Warburton et al., 1996).

Aim of the study and experimental design

A review of the neuropsychological and neuroimaging literature on nouns and verbs suggests the existence of both general and task-dependent grammatical class effects: the latter are most likely due to the fact that none of the tasks used so far permits a complete matching of all concomitant variables that can interfere with grammatical class effects (e.g., imageability and task complexity; see Crepaldi et al., 2006).

This circumstance calls for a factorial approach in which two lexical tasks are used; in such a design, any brain area underlying noun or verb lexical-semantic processing (irrespective of the concomitant variables) is expected to emerge in both conditions. A first task was chosen that permits a tight noun-verb matching of imageability and stimulus complexity (the Grammatical Class Switching Task, GCST); furthermore, picture naming of objects and actions (Picture Naming Task, PNT) was selected, as it stands out with regards to the amount of published work aimed at detecting behavioural and anatomical dissociations in noun and verb retrieval. Nevertheless, because of its intrinsic constraints, PNTs are imbalanced for some variables that can be matched in the GCST; in particular, stimuli available to elicit verbs and nouns in PNTs are imbalanced with regards to stimulus complexity and imageability. We therefore expected to observe grammatical class effects shared with the GCST as well as task-dependent grammatical class effects.

In conclusion, in order to examine the functional anatomical correlates of noun-verb processing, we adopted a factorial design with two tasks, both involving lexical-semantic processing with nouns or verbs. This design aims at identifying the brain areas that (i) show task-independent grammatical class effects (utilizing conjunction analyses between noun- and verb-specific areas observed in the two tasks) and (ii) are associated with task dependent responses (by determining task-by-grammatical-class interaction effects).

MATERIALS AND METHODS

Subjects

Twelve healthy, right-handed Italian students (F=6, M=6) aged between 20-32 years [mean=25.5, SD=3.36], with at least 15 years of education [mean=16.6, SD=0.60] participated in the experiment. None had any history of neurological disorders or learning disabilities; all gave their written consent to the experiment.

Materials

Task1: the Grammatical Class Switching Task (GCST)

45 Italian nouns and 45 corresponding verbs (e.g. *applauso* - *applaudire*, applause - to applaud; see Figure 2) were selected from the set used by Crepaldi et al. (2006). Each of the 45 noun-verb pairs were used to generate two different trials: in the noun-to-verb (N-to-V) condition, the participants were instructed to read the noun and to retrieve the corresponding verb silently, whereas in the verb-to-noun (V-to-N) condition, they were asked to read the verb and to retrieve the corresponding noun silently. The task was therefore composed of 90 trials, 45 of which elicited a verb, while the remaining 45 elicited a noun. The stimuli (font: Arial; size: 42; colour: black) were displayed in the centre of a computer screen on a white background; a question mark in the same font was added under each stimulus.

All nouns and verbs were given and requested in their morphological base form, i.e. the infinitival form for verbs and the singular form for nouns (in Italian nouns and verbs are always inflected, even in the base form); nouns were also preceded by the article in order to disambiguate them from homophonous/homographic verbs. Twenty-seven verbs belonged to the first conjugation (*-are* verbs; e.g., *saltare*, to jump), 13 verbs to the second conjugation (*-ere* verbs; e.g., *correre*, to run) and five verbs to the third conjugation (*-ire* verbs; e.g., *dormire*, to sleep); this distribution reflects the proportion of the three conjugations in the entire Italian verb set (*-are* verbs=70%; *-ere* verbs=19%; *-ire* verbs=11%; see the BDVDB database, Thornton et al., 1997).

As reported in Table 2, nouns and verbs were matched for imageability (estimated on the basis of a sample of 21 normal subjects along a seven-point scale), number of letters, age of acquisition (estimated on the basis of a sample of 20 normal subjects along a nine-point scale; Lotto, Dell'Acqua, & Job, 2001) and surface frequency (taken from De Mauro, Mancini, Vedovelli, & Voghera, 1993), while verbs have a higher number of syllables and have a significantly higher stem frequency than nouns (De Mauro, Mancini, Vedovelli, & Voghera, 1993). Both imageability and age of acquisition ratings were collected by asking volunteers to judge printed words.

Though the GCST may appear to be a task that can be solved by the application of a morphological routine, it does require lexical access. Indeed, the GCST cannot be carried out by applying derivational sub-word-level rules because Italian verbs do not offer any cue to predict the appropriate deverbal morpheme among the several alternatives available. Take the verbs *bombard-are* (to bomb), *calcol-are* (to calculate) and *cammin-are* (to walk), for example; they are approximately the same length and belong to the same conjugation, but are nominalized through entirely different morphemes (*bombard-amento*, bombardment; *calcol-o*, calculation; *cammin-ata*, walk). Therefore, the information on the correct derived forms must be stored at the lexical level, making lexical access necessary in order to carry out the noun-verb switch.

One may also argue that the activation triggered by the GCST reflects both noun and verb processing, as participants always read a noun when they were required to enunciate a verb, and a verb when they were required to enunciate a noun. However, the processing required by the input component of the GCST (the written cue) is very limited and much imaging evidence suggests that there is little activation for poorly processed components of a task (e.g., Rees, Frith and Lavie, 1997 or Rees and Lavie, 2001, for a review).

The Picture Naming Task (PNT)

The PNT was devised of 45 object and 45 action drawings taken from the picture set used by Crepaldi et al. (2006; see Figure 2).

All the items included in the study had a name agreement of at least 85% (see Crepaldi et al., 2006). Table 3 summarizes the mean values for word length (letters and syllables), oral stem and surface frequency, imageability, age of acquisition, picture typicality and picture complexity; the former five variables were measured with the same procedure used for the GCST stimuli, whereas picture typicality and complexity were rated on a 1-to-7 scale by 23 and 12 healthy volunteers, respectively. The two grammatical classes did not differ for oral word frequency, age of acquisition and picture typicality. As usual in PNTs, verbs were less imageable and pictorially more complex than nouns. Finally, verbs were slightly longer than nouns.

Experimental procedure

Subjects performed each experimental task three times prior to scanning in order to reduce uncertainty about the target response; these familiarization sessions were taken consecutively one to three hours prior to the fMRI scanning. During this phase, voice-onset times were recorded for each participant. The experimental procedure during this phase was the same as that used during the fMRI session; stimuli were presented in random order within each block in order to avoid sequence effects. The task order was balanced between the subjects in both the familiarization phase and in the fMRI session, with 6 participants performing the PNT before the GCST and 6 performing the GCST before the PNT.

During the fMRI session, stimuli were projected from a PC located outside the MR room, using Presentation 0.75 software. The stimuli were shown in the centre of a white screen. In each task the participants were exposed to the stimuli for one second, after which the screen went blank for one second (thus exposing the participants to one stimulus every two seconds). During the fMRI session subjects were instructed to perform each task silently in order to avoid artefacts due to mouth and head movements.

The fMRI design was based on alternating blocks of 10 scans of baseline and experimental tasks. Different baselines were used for the two experimental tasks; in particular, during the PNT rest period the subjects were shown a set of meaningless figures formed by scrambling the drawings used in the experimental condition. In addition, a geometric figure - either a 2 cm black square or a black circle 2 cm in diameter - was added to the centre of each scrambled picture and subjects were asked to name it (see Figure 2). As the scrambled stimuli were obtained from the experimental pictures, the elementary aspects of visual processing were matched between the experimental and the control condition.

During the GCST rest period, the subjects were shown a string of black squares with a circle in the central position or vice versa (Figure 2) and were asked to name the central geometrical figure. Ten series of strings of increasing length were used to balance the length of the words used in the experimental condition. In this case too a question mark was located under the string in order to balance the visual complexity of the stimuli used for the noun and verb condition.

fMRI data acquisition

MRI scans were performed on a 1.5 T Marconi-Philips *Infinion* Scanner, using an Echo Planar Imaging (EPI) gradient echo sequence (Flip angle 90° TE = 60msec, TR = 3050msec, FOV = 240x240, matrix = 64 x 64). The selected volume consisted of 26 contiguous transverse images (thickness = 5 mm; gap = 0 mm), acquired every 3.05 seconds. Each of the experiments described above generated 120 fMRI scans collected in alternating blocks of 10 baseline scans and 10 experimental task scans, each epoch lasting 30".

Data analysis

Behavioural data analysis

The raw data were averaged across subjects and items; two separate data sets were then created (by-subject and by-item). The RTs of one of the 12 subjects participating in the experiment were not considered in the analyses as some artefacts occurred during the familiarization phase and so RT measurements were not completely reliable for this subject. Mean RTs at more than two standard deviations from the individual subject/item mean were also excluded from the analysis; this resulted in the elimination of 2% of the data from the by-item dataset and of 5% of the data from the by-subject dataset. The mean RTs were then inverse-transformed to obtain a more Gaussian-like distribution. In order to assess the effects of Task (2 levels; GCST vs. PNT), Session (3 levels: training session 1 vs. training session 2 vs. training session 3), Grammatical Class (2 levels: nouns vs. verbs) and their interactions, a three-way (3x2x2) repeated-measure ANOVA was conducted on the by-subject dataset, whereas a three-way mixed-design ANOVA was run on the by-item dataset.

Finally, two stepwise multiple regression analyses (MRA) were carried out on the inverse-transformed RTs for the PNT and the GCST (there is no *a priori* reason to assume that the same variables influenced the RTs in the two tasks), using the lexical-semantic variables as covariates.

fMRI data analysis

First, a standard pre-processing was performed; this included the realignment of fMRI scans within each session and the normalization of the realigned images into the standard stereotaxic space. The stereotaxically normalized scans were then smoothed through a Gaussian filter of 10x10x10 mm to improve signal-to-noise ratio. The statistical analysis was performed by applying a general linear model: conditions were modelled in a block-design and the BOLD signal was convolved with a standard HRF as implemented in SPM2 (Friston, Holmes, Worsley, Poline, Frith, & Frackowiak, 1995). Global differences in fMRI signal were compensated using proportional scaling for all voxels. High-pass filtering was used to remove confounding contributions to the fMRI signal, such as, for example, physiological noise from cardiac and respiratory cycles. The statistical analyses involved two steps. First, on each subject a fixed effect analysis was performed, in which condition-specific effects were calculated. These analyses generated contrast images containing the statistical information relative to the fMRI signal change as observed for a given statistical comparison, for each individual participant. Further, second-level ANOVAs conforming to random effect analyses were performed, in order to permit a generalization to the population level of the statistical inferences. The following condition-specific effects were estimated for each subject at the fixed effect analyses stage: (i) nouns-minus-baseline in the PNT; (ii) nouns-minus-baseline in the GCST; (iii) verbs-minus-baseline in the PNT; (iv) verbs-minus-baseline in the GCST. These effects are relatively unspecific as they are confounded with the functional anatomical correlates of the PNT and GCST. To characterize within these patterns those more specifically associated with noun and verb retrieval, and their interaction with task, the following comparisons were also performed:

(v) simple effects of nouns-minus-verbs and of verbs-minus-noun in the PNT;

(vi) the same effects in the GCST.

The contrast images derived from the above first-level analyses were then brought to a random-effect second level ANOVA. At this stage, the same effects were calculated at a group level. In addition we also calculated:

(vii) a conjunction of the specific activation of verbs-minus-noun and of nouns-minus-verbs across both tasks;

(viii) a task-by-grammatical-class interaction effects.

In these second level group analyses, direct comparisons (e.g. verbs-minus-nouns in the PNT) were masked (using an inclusive mask, thresholded at $p<0.05$) on the effect of the task of interest minus the baseline (e.g.: verbs-minus-nouns for the PNT masked on verbs-minus-scrambled pictures from the PNT). This was done to ensure that the activations emerging in the direct comparisons were not due merely to a de-activation in the baseline condition task; by doing so, any reported effect for a particular task effectively describes an activation that would also be replicated, at least as a trend, in a comparison with a further baseline.

For the same reason, the effects described at points (vii) and (viii) were masked on the four relevant simple effects (the threshold for the inclusive masks was $p< .05$): for example the conjunction of verbs-minus-nouns across tasks, namely, the conjunction of verbs-minus-nouns in PNT and verbs-minus-nouns in GCST, was masked on verbs-minus-baseline in PNT, verbs-minus-nouns in PNT, verbs-minus-baseline in GCST and verbs-minus-nouns in GCST.

All statistical comparisons are reported at a threshold of $p<.001$ (uncorrected). The tables also indicate which foci survived the corrections for multiple comparisons offered by SPM2, i.e. the family-wise error rate (FEW) (Kiebel et al., 1999) and the false discovery rate (FDR) corrections (Genovese et al., 2002).

RESULTS

Behavioural results

Table 4 summarizes the mean RTs obtained by the subjects in the two tasks and the two grammatical classes along the three familiarization sessions.

The 3x2x2 repeated-measures ANOVA (by-subject analysis) indicates a significant effect of session ($F[2,18]=13.26$; $p< .001$), task ($F[1,9]=5.44$; $p< .05$) and task-by-grammatical-class ($F[1,9]=54.68$; $p< .001$). The mixed-design ANOVA carried out on the by-item dataset shows exactly the same effects. Interestingly, the task-by-grammatical-class interaction reflects faster response to nouns in the PNT task ($t = 3.18$, $df = 87$, $p < .005$), but faster responses to verbs in the GCST task ($t = -7.09$, $df = 85$, $p < .001$; see Table 4).

Table 5 and Table 6 report the results of the stepwise multiple regression analyses for the GSCT and the PNT respectively. Surface and stem frequency were so tightly correlated in both tasks that their individual contributions could not be assessed in a multiple regression analysis (Table 7); thus, only stem frequency was inserted in the regression models. A tight correlation also emerged between number of letters and number of syllables; thus, only number of letters was included in the linear models. None of the variables influenced RTs in the GCST (Table 5), while only imageability was a significant predictor in the PNT (Table 6).

fMRI results

The grammatical class switching task

The simple effect of nouns (minus baseline) showed significant activation of a large left frontal network, of the left superior temporal pole, the right and left inferior temporal gyrus, the left inferior parietal lobule and the left superior, middle and inferior occipital gyri. The verbs-minus-baseline comparison was associated with increment of the BOLD signal in the precentral gyrus bilaterally, the left supplementary motor area (SMA), the right middle temporal pole, the left superior temporal gyrus, the middle and inferior temporal gyri bilaterally, the left supramarginal and angular gyri and the lingual gyrus bilaterally (see Table 8 and Figure 3).

Direct comparisons between the two grammatical classes revealed that, when compared to verbs, nouns activate the left inferior frontal gyrus, the left inferior parietal lobule, the left precuneus and the left middle and superior occipital gyri (Table 6 and Figure 4), while verbs were associated with increased BOLD signal in a bilateral frontal network - including the superior frontal gyrus, the precentral gyrus and the SMA - and in a right parietal network - including the postcentral gyrus, the paracentral lobule and the precuneus (see Table 8 and Figure 3).

The picture naming task

The simple effect of nouns versus the corresponding baseline was associated with an increase in the BOLD signal in the right inferior temporal gyrus, in the left superior occipital gyrus and in the inferior occipital gyrus bilaterally, whereas verbs versus the corresponding baseline showed activation not only in the right and left occipital regions and in the right inferior temporal gyrus, but also in the left inferior frontal gyrus, in the right cuneus, in the left fusiform gyrus and in the lingual gyrus bilaterally (see Table 9 and Figure 3).

Direct comparisons showed that while nouns did not activate any area to a larger extent than verbs did, these latter were associated with larger activation in the left inferior frontal gyrus, in the left insula and in posterior regions including the right and left superior and middle occipital gyri, the left lingual gyrus, the bilateral middle temporal gyrus, the right inferior temporal and the dorsal part of the right and left posterior parietal gyri (Table 9 and Figure 3).

Across-task activations for nouns and verbs

These activations were explored through the conjunction analyses described in the methods section. In both tasks verbs were associated with a significant increment of the BOLD signal in the precentral and postcentral gyri bilaterally, in the right SMA, in the right inferior parietal lobule and, bilaterally, in the paracentral lobule, in the superior parietal lobule and in the precuneus (see Table 10 and figure 4). On the contrary, no significant activation emerged when combining nouns-minus-verbs and nouns-minus-baseline conditions in the PNT and in the GCST.

Task-by-grammatical-class interaction effects

Significant task-by-grammatical-class interaction effects emerged in the left inferior frontal cortex, the left insula, the left inferior temporal gyrus and the occipital cortex bilaterally: these areas were systematically more active for verb retrieval in the PNT and for noun retrieval in the GCST (see Table 11 and Figure 5). On the contrary, there was no opposite interaction effect, i.e. no areas were more active for nouns in the PNT and for verbs in the GCST.

DISCUSSION

As reported in the Introduction, previous evidence on the brain areas underlying noun and verb processing is far from representing a clear picture; this may be because in most studies (i) the specification of the cognitive processes entailed by the experimental and control tasks were sub-optimal and (ii) the experimental designs were not controlled for confounding factors, like imageability and task complexity.

Our study aims at assessing these issues by investigating noun and verb retrieval while controlling for spurious factors. We used two different tasks for this purpose: a noun and verb production task (Grammatical Class Switching Task, GCST) and the most widely used picture naming task (PNT). This experimental design allowed us to determine which brain regions are consistently associated with nouns or verbs across tasks; these areas were identified by conjunction analyses of the grammatical-class-specific activations in the two tasks. The same design allowed us to identify those brain regions that show a task-dependent grammatical class effect or, in other words, a task-by-grammatical-class interaction effect. Interestingly, the fMRI interaction effects were associated with behavioural effects, which we will take as the starting point of our discussion.

Behavioural data: the RTs analysis

The analysis of the RTs reveals a consistent and significant shortening during the familiarization phase. Moreover, there was no interaction between session and grammatical class or task*;* this lack of interaction shows that RTs shortened homogeneously along the familiarization sessions without introducing any artificial distortion between different experimental conditions. These results suggest that pre-fMRI familiarization was not associated with a grammatical-class specific adaptation in the functional imaging results.

The RT analysis also revealed that nouns were retrieved faster than verbs in the PNT and slower than verbs in the GCST. This interaction effect is in line with the task-dependent grammatical class effects described in three patients by Crepaldi et al. (2006) and can be explained as follows. Slower verb retrieval in the PNT can arguably be attributed to the fact that the relationship between verbs and their corresponding pictorial representation is weaker than it is for nouns. Indeed, as already mentioned in the Introduction, it is not possible to depict the action of "eating" *per se*; at best the sketch would represent a person with his/her mouth open, some food, and maybe a table and a chair at which and on which the person is sitting; but the actual action of "eating" is more than the sum of the individual agent, theme and possible adjuncts. In other words, in order to retrieve a verb in a PNT, the arguments of the event (e.g. agent, theme/goal) must be identified, their relationships processed, the underlying action singled out and the corresponding lexical entry retrieved. All these cognitive steps have a cost in terms of time and do determine a higher task demand.

On the other hand, slower RTs for nouns were not necessarily predicted in the GCST, but they can be explained as follows. Italian has more than ten de-verbal derivational suffixes (e.g. *-io* in *mormorio-mormorare* (to mumble), *-ime* in *mangime-mangiare* (to eat), *-mento* in *bombardamento-bombardare* (to bomb), *-anda* in *bevanda-bere* (to drink), *-nza* in *speranza-sperare* (to hope), *-ta* in *fermata-fermare* (to stop), *-uta* in *caduta-cadere* (to fall), *-zione* in *informazione-informare* (to inform)); therefore, when generating a noun from a verb, there are many possible alternatives, of which only one is an existing noun. On the contrary, verbs have only three possible endings (*-are*, *-ere*, *-ire*). As a result, the search for nouns is more demanding than for verbs, and this may have determined longer RTs when producing nouns in the GCST.

In both cases (i.e., verb production in the PNT and noun production in the GCST), a higher cognitive demand can account for the different response times elicited by the two grammatical classes.

However, the grammatical-class-by-task interaction may also depend on the effect of lexical-semantic variables, particularly of imageability (unmatched in the PNT) and word frequency (unmatched in the GCST) and so a Multiple Regression Analysis (MRA) was carried out to assess the impact of these factors. Although MRA suggests a role for these variables (imageability is a significant predictor in the PNT), in themselves they are not sufficient to explain the interaction effect for at least two reasons. While the imbalanced variable influences RTs in the PNT (where imageability *is* a significant predictor), this is not the case in the GCST (where word frequency *is not* a significant factor); moreover, neither imageability nor word frequency (nor any other variable) explains RTs in both tasks.

Altogether, the interaction which emerges in the behavioural data seems best explained in terms of task demand, although imageability and frequency may play an additional (though less relevant) role.

Neuroimaging data

The exploration of the simple effects reported in Tables 8 and 9 and in Figure 3, i.e., the comparisons against baselines and the direct comparison between "noun" and "verb" scans, shows a large number of brain regions, some of which are systematically associated with a given grammatical class, while some other appear to activate in a task-dependent manner.

The following discussion will briefly remark on the brain areas activated in the single tasks and then will focus on the conjunction analysis of the grammatical class effects across tasks and on the analysis of the task-by-grammatical-class interaction effects: these latter allow us to make inference about commonalities and differences between grammatical classes, tasks, and their interactions.

Neuroimaging data: the GSCT

When compared with the baseline, noun retrieval in the GCST activates a left-lateralized pattern of areas, including the inferior frontal gyrus, the middle frontal gyrus, the precentral gyrus, the temporal pole, the inferior temporal gyrus, the inferior parietal lobule and the superior, middle and inferior occipital gyri (Table 8). This very extensive pattern of activation for nouns is quite in line with the brain areas described in a lexical decision task by Fujimaki, Miyauchi, Putz, Sasaki, Takino, Sakai, & Tamada (1999) and is larger than those usually emerging in PNTs (e.g. Tranel et al., 2005a). Verbs in the GCST were also associated with a fairly wide network, involving some areas that were activated also by nouns (left precentral gyrus, left and right inferior temporal gyrus and bilateral lingual gyrus), but also others that were not (left SMA, middle cingulate gyrus and left angular and supramarginal gyri; see Table

8). Compared with verbs, nouns activate the left inferior frontal gyrus, the left inferior parietal lobule and the left precuneus, whereas, compared with nouns, verbs activate the precentral gyrus and the SMA bilaterally, and a right-hemisphere parietal network including the post-central gyrus, the paracentral lobule and the precuneus (Table 8).

The noun- and verb-related networks that emerge in the GCST are not completely consistent with the brain areas frequently reported as specific for one of the two grammatical classes. For instance, the left inferior frontal gyrus has been mostly reported to be associated with verbs (e.g. Chao & Martin, 2000, Tyler et al., 2003). Our results rather agree with those reported by Bedny & Thompson-Schill (2006), which reveal complex grammatical-class-by-imageability interaction, according to which the left inferior frontal gyrus is more active for nouns if the items are low in imageability, but for verbs if the items are high in imageability. As our GCST stimuli were particularly low in imageability, a noun-specificity for the left inferior frontal gyrus is not surprising. Moreover, the GCST reveals that the parietal areas play an important role in verb processing; although a number of experiments have showed parietal activations for verbs (e.g. Shapiro, Moo, & Caramazza 2006; Chao & Martin, 2006), these areas have always been found in association with more predominant frontal networks and, consequently, their cognitive role in verb processing has been only marginally addressed.

Neuroimaging data: the PNT

Previous neuroimaging studies on noun retrieval that used a PNT to elicit responses have highlighted the contribution of several left-hemisphere areas, including the parahippocampal and fusiform gyri, the inferior temporal gyrus, the medio-temporal gyrus, the insula, the inferior frontal cortex and the precentral gyrus (e.g. Chao & Martin, 2000; Tranel, Grabowski, Lyon, & Damasio, 2005; Saccuman, Cappa, Bates, Arevalo, Della Rosa, Danna, & Perani, 2006). A very different pattern emerged in the present study when the noun-retrieval condition was compared with the baseline: an activation of the right inferior temporal gyrus, of the left superior occipital gyri and of the inferior occipital gyrus bilaterally was found (Table 9). This difference could be due to the fact that previous studies used passive viewing as a baseline, whereas the control task employed in this study required the silent retrieval of a semi-automatic response (either "square" or "circle"), arguably allowing the subtraction of any of the post-lexical cognitive processes, such as phonological implementation, syllabification and, eventually, articulation.

When comparing the action-naming condition to the baseline, a significant activation emerged in the left inferior frontal gyrus, the right inferior temporal gyrus, the right cuneus, the bilateral superior, middle and inferior occipital gyri, the left fusiform gyrus and the lingual gyrus bilaterally (Table 9). As the baseline subtracted the contribution of post-lexical processes from the activation (see previous paragraph), these results can be properly compared only with those from Damasio, Grabowski, Tranel, Ponto, Hichwa, & Damasio (2001). The patterns emerging in the two studies only overlap in the left inferior frontal gyrus. We found a verb-related activation of the most posterior portion of the right inferior temporal gyrus, which has not been observed previously; however Damasio et al. (2001) did find significant activation slightly further up in the right middle occipital gyrus at its junction with the middle temporal gyrus.

Compared to verbs, nouns did not activate any specific brain region. Verbs, on the contrary, were associated with increased activation of a rather large bilateral pattern including the left inferior frontal gyrus, the left insula, the left middle temporal gyrus, the right inferior temporal gyrus, the bilateral middle occipital gyri and the left lingual gyrus (see Table 9). These findings seem to suggest that noun retrieval does not recruit different and specific areas as compared to verbs and is sub-served by a somewhat smaller and quantitatively less activated network in the same brain regions: this result is in line with the conclusions drawn by Warburton et al. (1996). For what concerns the verb-specific areas, occipital activation is arguably due to the greater stimulus complexity characterizing action pictures compared to object pictures; in fact, action pictures always include an agent and often a theme/goal. The verb-specific activation found in the left inferior frontal gyrus and the left insula is in line with a number of previous studies (e.g. Perani, Cappa, Schnur, Tettamanti, Collina, Rosa, & Fazio, 1999; Tyler et al., 2004), but has never been reported in verbs-minus-nouns direct comparison in picture naming. Only Tranel et al. (2005b) found left middle temporal activation in the verbs-minus-nouns direct comparison.

The conjunction analyses: Grammatical class replicable effects

The conjunction analysis carried out for verbs showed an across-task replicable verb-specific activation of the right and left precentral and postcentral gyri, of the right SMA and of the paracentral lobule, the superior parietal lobule, the inferior parietal lobule and the precuneus bilaterally. Since the premotor and superior parietal areas are known to be crucial for the formation of motor representation in observational learning (e.g. Frey & Gerry, 2006), for visuo-motor integration and for the planning of object-related action (Grefkes & Fink, 2005), our results indicate that lexical and lexical-semantic representation of verbs are strictly connected with action-oriented (visuo-)spatial brain networks. Furthermore, it should be considered that our tasks included verbs with a prominent motor component, like *nuotare* (to swim) and verbs denoting actions which require finely-tuned hand movements, like *accarezzare* (to caress), but also verbs denoting more automatic actions like *starnutire* (to sneeze) and verbs denoting actions that can be realized by fully different motor engrams (like *sollevare,* to lift, in lifting a finger, lifting an arm, lifting a couch or lifting a case through a pulley), making their conceptual representation unlikely to be based on specific motor representations. Therefore, our results suggest that lexical-semantic verb representations are related to action-oriented spatial knowledge even when verbs with low degree of actionality are considered together with proper action verbs. A further experiment using separate groups of verbs with different degree of actionality should be carried out to test whether this superior parietal verb-related network can be further dissected into smaller functional subsets.

The activation emerging in the precentral and postcentral gyri is in line with the results reported by Hauk, Johnsrude & Pulvermuller (2004) and seems to confirm a relationship between lexical-semantic verb representations and sensori-motor knowledge. However, the concomitant emergence of extensive more posterior parietal activation seem to confirm a primary role of these latter areas in storing (and/or processing) action-related lexical and lexical-semantic knowledge.

We found no noun-specific activation across tasks; this was evident from the conjunction analyses that failed to reveal a noun-specific brain network activated over and above the verb network in both the GCST and the PNT. This finding is line with the results reported by Hernandez, Dapretto, Mazziotta and Bookheimer (2001) and by Tyler et al. (2001). This lack of noun-specific areas may be explained at least in part by the different imageability ratings of nouns in the PNT (highly imageable) and in the GCST (poorly imageable, as they had to be matched with verbs). This interpretation is suggested by Bedny & Thompson-Schill's (2006) results, which show that both noun- and verb-specific activations vary according to the imageability of the stimuli.

The task-by-grammatical-class interaction: The role of the left inferior frontal gyrus

The left inferior frontal gyrus and the left insula are strongly activated by verbs in the PNT; these areas could therefore be considered as verb-specific. This hypothesis would imply the activation of these areas in any task involving lexical access to verbs, and in particular in the GCST. However, as can be seen from Table 10, this is not the case.

As proposed by Thompson-Schill et al. (1997), Snyder et al. (2007) and Bedny et al. (2007), there is an alternative hypothesis suggesting that activation in the left inferior frontal gyrus reflects higher cognitive demand of the task and the presence of several different alternatives to select among rather than verb-specific lexical-semantic processing. As already argued in the Introduction and in the Discussion of the behavioural data, verbs impose higher task demand than nouns in the PNT, due to a less direct relationship between lexical entries and the corresponding pictures. Nouns, on the contrary, impose higher selection demands in the GCST in Italian, since a higher number of derivational affixes are available to produce a noun from a verb than a verb from a noun. In addition, in the PNT verbs were less imageable and longer than nouns, whereas in the GCST nouns were less frequent than verbs; this mismatch may have contributed to further increase the task demand imposed by verbs in the PNT and by nouns in the GCST.

Altogether, the fMRI data support the hypothesis that activation of the left inferior frontal gyrus reflects task demand and is therefore associated with verbs in the PNT and with nouns in the GCST. This is also perfectly in line with the behavioural data: the double dissociation observed between the two tasks in the RT analysis reflects the different processing load for nouns and verbs and fully parallels the task-by-grammatical-class interaction found in the left inferior frontal gyrus and in the left insula.

This interpretation is also in line with the neuropsychological study by Crepaldi, Aggujaro, Arduino, Zonca, Ghirardi, Inzaghi et al. (2006). As for the present study, these authors have tested noun-verb dichotomy with two different tasks: a classical Picture Naming Task (PNT) and the Noun and Verb Retrieval task in Sentence Context (NVR-SC), a task that is very similar to the GCST. Three patients were more impaired for verbs in the PNT, but for nouns in the NVR-SC; considering the similarity between the NVR-SC and the GCST, Crepaldi et al.'s (2006) results mirror the grammatical-class-by-task interaction observed in the present study (both in terms of fMRI and behavioural data) and gives further evidence of task-dependent grammatical class effects.

CONCLUSION

Brain areas associated with either noun or verb processing depend largely on the specific task used to elicit their retrieval and may be influenced by the lower degree of imageability and the higher stimulus complexity characterizing verbs in picture naming.

In this study we showed that bilateral premotor and superior parietal activation emerges in relation to verbs across both tasks; this suggests that verb representation relies on action-oriented (visuo-)spatial knowledge.

Moreover, the task-by-grammatical-class interaction clearly shows that the activation of the left inferior frontal gyrus and of the left insula, which have been frequently found to be crucial for verb processing, is associated with verb retrieval in the PNT, but with noun retrieval in the GCST, mirroring the double dissociation that emerged in the RT analysis between nouns and verbs in the two tasks. This observation, together with theoretical considerations regarding the cognitive processes underlying noun and verb retrieval in the PNT and in the GCST, suggests that activation in the left inferior frontal gyrus and in the left insula reflects higher cognitive demands of the task rather than a verb-specific lexical or lexical-semantic.

FIGURES AND TABLES

Figure 1. Brain areas found to be related to either verbs or nouns in the past literature. Different symbols represent different baseline and experimental tasks; activation for verbs is drawn in orange, that for nouns in blue.

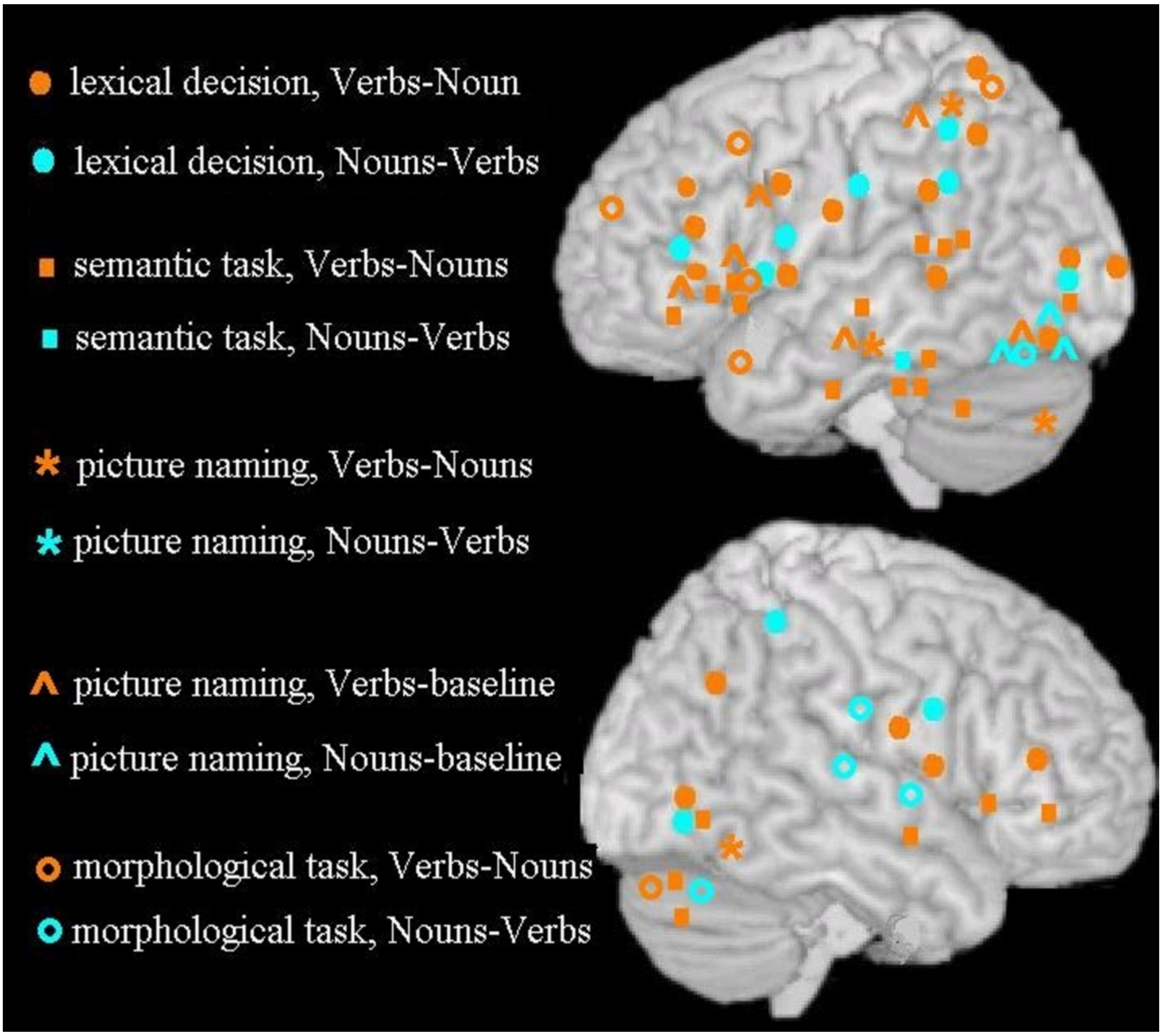

Figure 2. Stimulus examples for the experimental and baseline conditions.

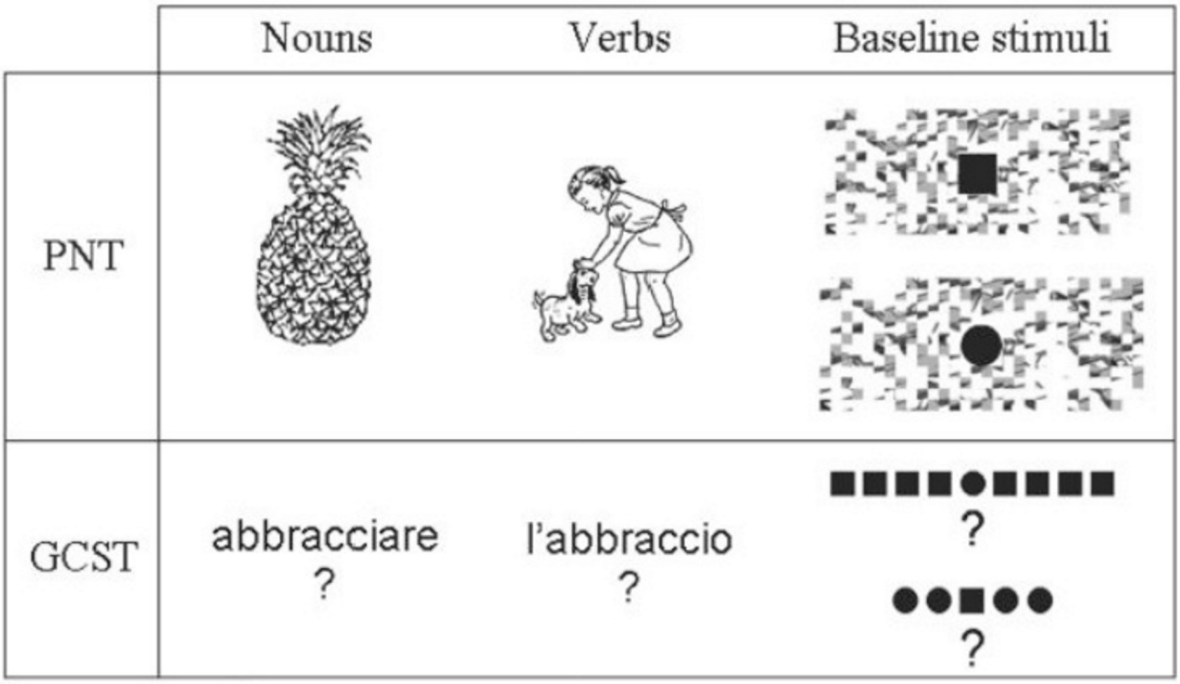

Figure 3. Brain areas associated with nouns or verbs in the PNT and in the GCST. (A) nouns-minus-baseline (blue), verbs-minus-baseline (orange) in the PNT; (B) nouns-minus-verbs (blue), verbs-minus-nouns (orange) in the PNT; (C) nouns-minus-baseline (blue), verbs-minus-baseline (orange) in the GCST; (D) nouns-minus-verbs (blue), verbs-minus-nouns (orange) in the GCST.

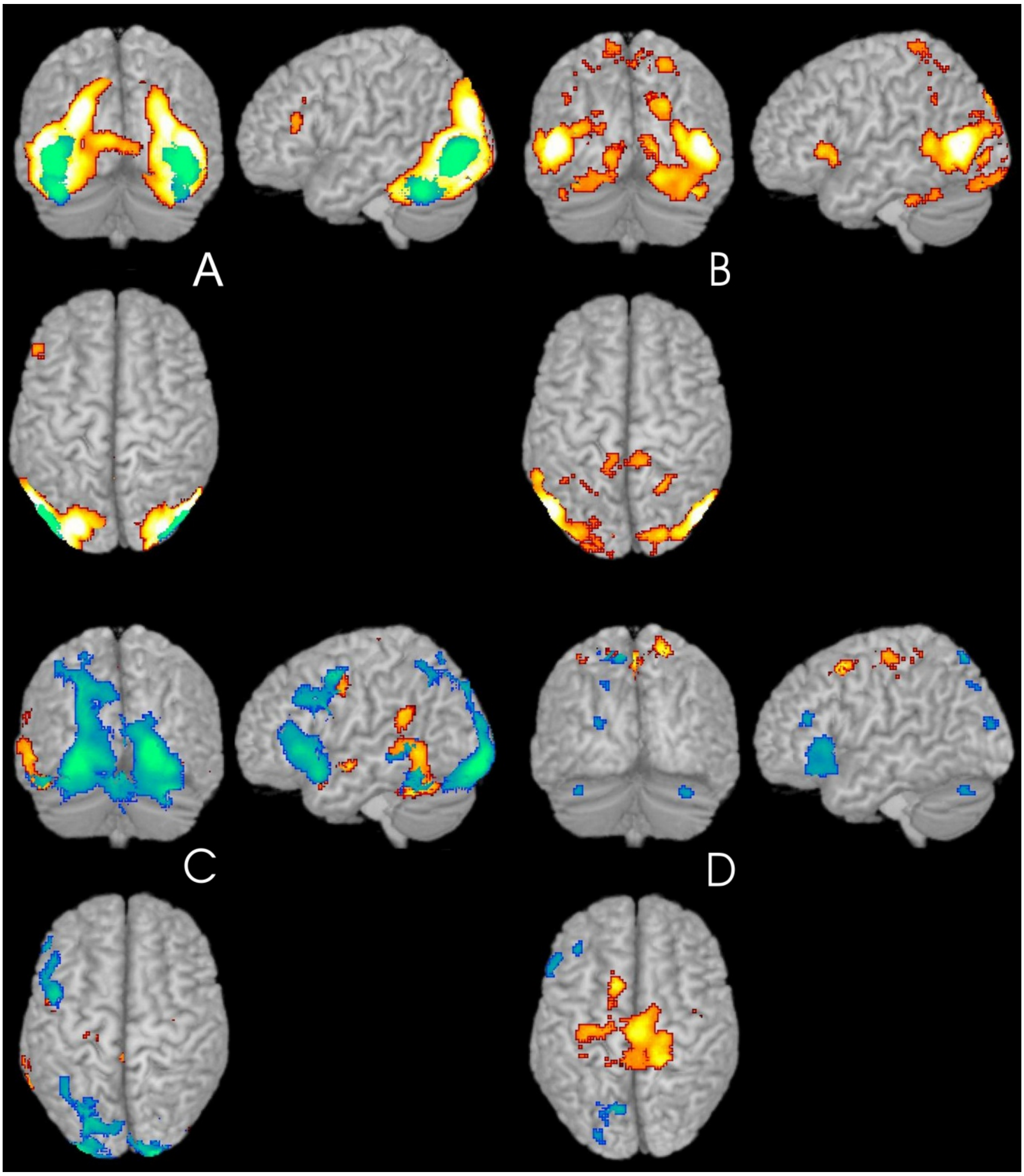

Figure 4. Conjunction analyses results: the brain regions consistently associated with verbs in both the PNT and the GCST are reported. The plot indicates the mean BOLD signal at the stereotactic coordinates x=6, y=-40, z=60 (right precuneus).

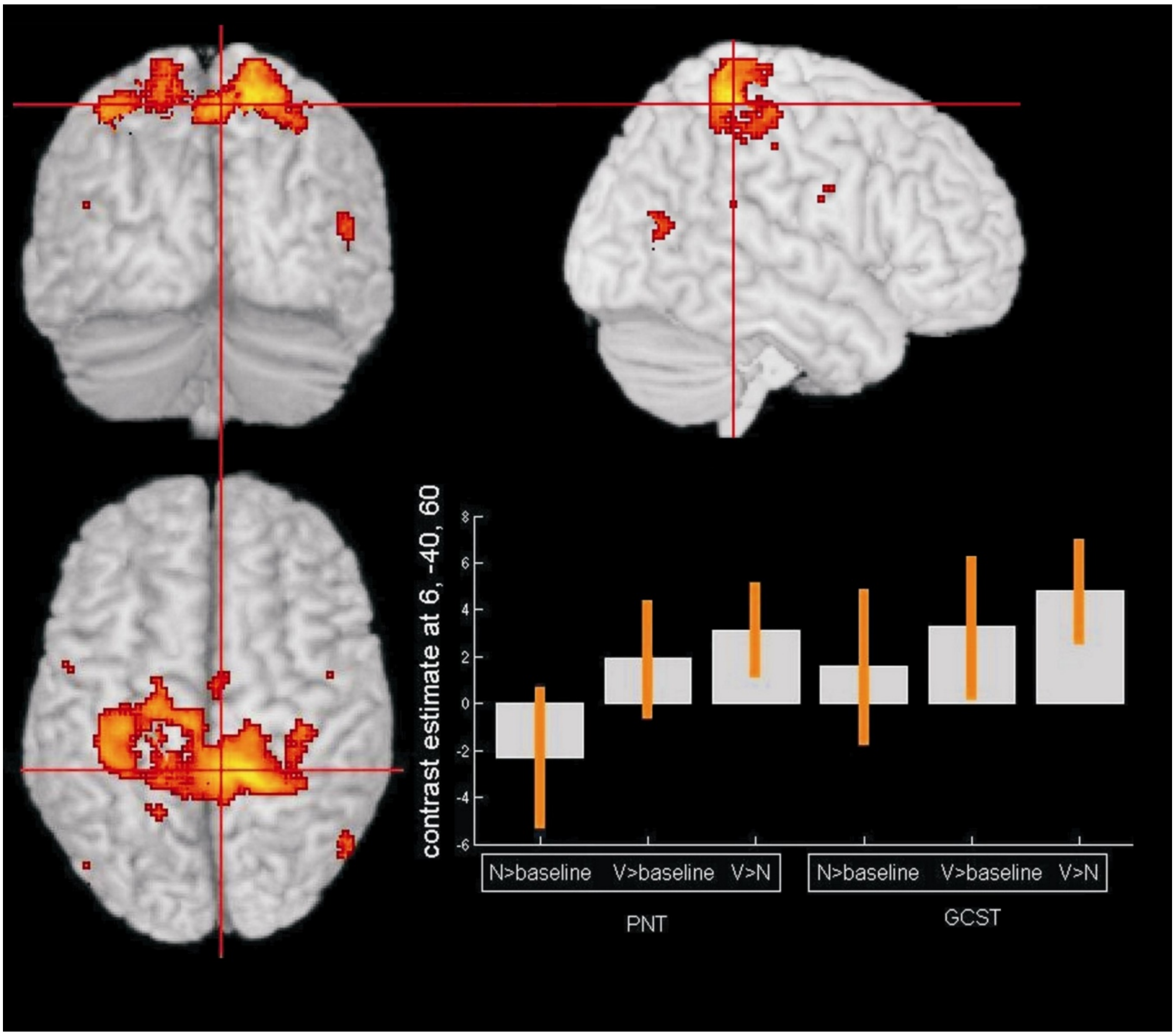

Figure 5. Grammatical-class-by-task interaction effect: the brain areas associated with verbs in the PNT and with nouns in the GCST are reported. The plot indicates the mean BOLD signal at the stereotactic coordinates x=-52, y=32, z=14 (left inferior frontal gyrus).

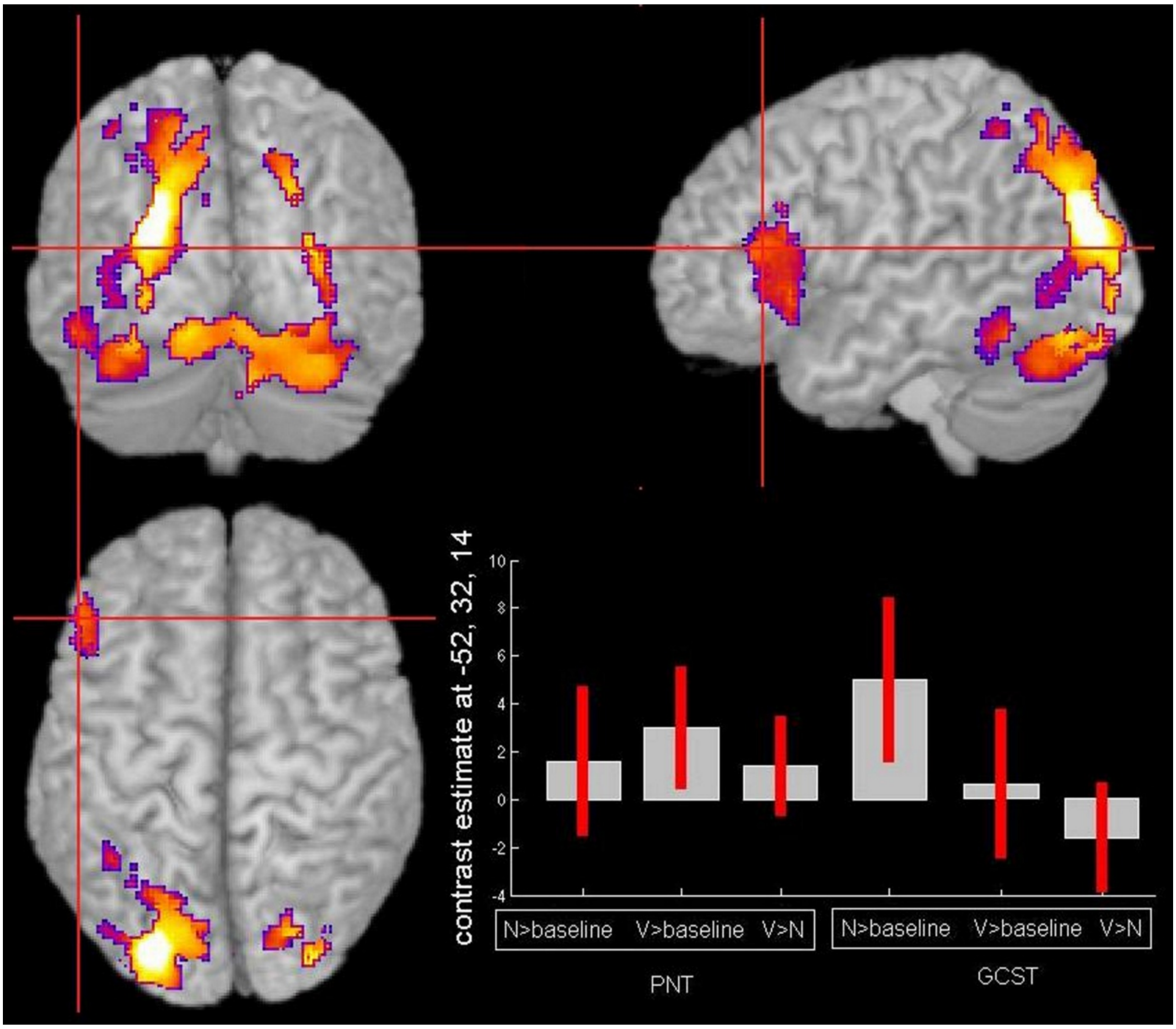

Table 1. PET and fMRI studies on nouns and verbs reported so far in the literature.

Authors	Technique	Sample size	Threshold	Design	Experimental task	Baseline	Contrast	Area
Perani et al. (1999)	PET	14	.001 uncorrected	Block design	Lexical decision	Letter detection task	Nouns-Verbs	No area
							Verbs-Nouns	L mid. and inf. Frontal gyrus; L sup Parietal lobule; L mid. and inf. Temp gyrus; L inf. Occipital gyrus.
Fujimaki et al. (1999)	fMRI	7	Cross-correlation coefficient, equivalent to .005 uncorrected	Block design	Lexical decision	Line orientation judgement	Noun-baseline	L Broca's area, L Insula, L ant. Cingulate sulcus, Precentral sulcus (bilaterally), L Postcentral sulcus, bilateral Intraparietal sulcus, L Supramarginal gyrus, bilateral Occipito-Temporal sulcus, R BA 46-47
							Verb-baseline	Bilateral Broca's area, Insula and BA 46, bilateral Precentral sulcus, L Postcentral sulcus, bilateral Intraparietal sulcus, L Supramarginal gyrus, Precuneus, bilateral Occipito-temporal sulcus.
Tyler et al. (2001)	PET	9	.05 corrected	Block design	Lexical decision	Letter detection task	Verbs-Nouns	R substantia nigra
							Nouns-Verbs	No area
					Semantic categorization task	Letter categorization task	Verbs-Nouns	L BA 20/37
							Nouns-Verbs	No area
					Conjunction analysis		Verbs-Nouns	No area
							Nouns-Verbs	No area
Tyler et al. (2003)	fMRI	12	.001 uncorrected (.05 at cluster level)	Event-related	Semantic categorization task	Letter categorization task	Verbs(tools)-baseline	L inf. Frontal gyrus, R ant. Cingulate gyrus, L Fusiform and Parahippocampal gyrus, L Lingual gyrus, R inf. Frontal gyrus, R sup. temporal gyrus, R Cerebellum.
							Verbs(biological)-baseline	L inf. Frontal gyrus, L sup. Temporal gyrus, L Fusiform gyrus, L Parahippocampal gyrus. L mid. Temporal gyrus, L inf. Temporal gyrus, Cerebellum bilaterally

Table 1 (follows)

Authors	Technique	Sample size	Threshold	Design	Experimental task	Baseline	Contrast	Area
Grossman et al. (2002)	fMRI	16	.001 uncorrected	Block design	Pleasantness judgement	Pseudoword passive viewing	Verbs-baseline	L postero-lateral Temporal cortex, Bilateral ventral Temporo-Occipital cortex, Bilateral Prefrontal cortex
Tyler et al. (2004)	fMRI	12	.001 uncorrected (.05 at cluster level)	Event-related	Semantic categorization task	Letter categorization task	Verbs-Nouns	L inf. Frontal gyrus
Bedny et al. (2006)	fMRI	13	.05 corrected	Event-related	Semantic matching	Identity judgement on pseudowords	Verbs-Nouns	L sup. Temporal gyrus, L post. Cingulate
							Nouns-Verbs	L inf. Frontal gyrus, L inf. Temporal gyrus
Chao et al. (2000)	fMRI	10	.001 uncorrected	Block design	Picture naming	Passive viewing of scrambled stimuli	Verbs-baseline	L inf. Frontal gyrus, L insula, L ventral Premotor cortex, L post. Parietal cortex
Damasio et al. (2001)	PET	20	.05 corrected	Block design	Picture naming	Orientation judgement of unknown faces	Verbs-baseline	L Frontal operculum, L post. Mid. Frontal gyrus, L infero-temporal, L and R inf. Parietal lobule, L and R supramarginal gyrus
Tranel et al. (2005a)	PET	10	.05 corrected	Block design	Picture naming	Passive viewing of scrambled stimuli	Nouns(tools)-baseline	L post. lat. Infero-temporal
							Nouns(animals)-baseline	L ant. ventral Infero-temporal
Saccuman et al. (2006)	fMRI	13	.001 uncorrected	Event-related	Picture naming	None	Verbs-Nouns	L intra-parietal sulcus, L Cerebellum, R Fusiform gyrus
							Nouns-Verbs	R Cuneus, R post. Cingulate cortex, R Caudate nucleus
Tranel et al. (2005b)	PET	10	.05 corrected	Block design	Picture naming	Orientation judgement on unfamiliar faces	Nouns(tools)-baseline	L post. ventral Infero-temporal
							Verbs-baseline	L Frontal Operculum, L mid. Temporal, L post. lat. infero-temporal
							Verbs-Nouns(tools)	L mid. Temporal

Table 1 (end)

Authors	Technique	Sample size	Threshold	Design	Experimental task	Baseline	Contrast	Area
Shapiro et al. (2005)	PET	12	.001 uncorrected	Block design	Word and pseudoword inflection task	Pseudoword reading	Verbs-Nouns	L sup. Frontal gyrus, L inf. Frontal gyrus, R cerebellum
							Nouns-Verbs	L Fusiform, R mid. sup. Temporal gyrus, R Insula, R Cerebellum
							(Verbs-Nouns) and (Pseudoverbs-Pseudonouns)	L sup. Frontal gyrus
							(Nouns-Verbs) and (Pseudonouns-Pseudoverbs)	R mid. sup. Temporal gyrus, L fusiform gyrus
Shapiro et al. (2006)	fMRI	10	.005 uncorrected	Event-related	Regular/irregular abstract/concrete word inflection	Fixation	Nouns-Verbs	L Fusiform gyrus
							Verbs-Nouns	L Prefrontal cortex, L sup. parietal
			.01 uncorrected				(Verbs-fixation) and (Nouns-fixation)	L inf. Premotor and Prefrontal cortex, L mid. Temporal gyrus, L Temporo-occipital junction

Table 2. Lexical-semantic variables for nouns and verbs in the GCST (mean ± standard deviation).

Variable	*Verbs (n=45)*	*Nouns (n=45)*	*t Test*	*p*
Oral stem frequency	36.53 ± 77.66	11.02 ± 15.28	2.16	<.05
Oral word surface frequency	8.24 ± 10.84	8.10 ± 16.23	.48	n.s.
Imageability	4.52 ± 0.68	4.30 ± 0.92	1.28	n.s.
Number of letters	8.06 ± 1.54	7.71 ± 2.41	.24	n.s.
Number of syllables	3.47 ± 0.59	3.09 ± 0.97	2.23	<.05
Age of acquisition	4.18 ± 1.43	3.77 ± 1.31	-1.42	n.s.

Table 3. Lexical-semantic variables for nouns and verbs in the PNT (mean ± standard deviation)

Variable	*Verbs (n=45)*	*Nouns (n=45)*	*t Test*	*p*
Oral stem frequency	14.51± 22.25	8.02 ± 15.28	1.56	n.s.
Oral word surface frequency	6.66 ± 12.02	5.97 ± 10.68	.25	n.s.
Imageability	4.74 ± 0.70	5.99 ± 0.39	-10.46	*<.001*
Number of letters	7.91 ± 1.50	6.91 ± 1.74	2.91	*<.01*
Number of syllables	3.36 ± 0.57	2.91 ± 0.76	3.13	*<.005*
Age of acquisition	3.62 ± 1.17	3.42 ± 1.04	.85	n.s.
Picture typicality	5.59 ± 0.81	5.81 ± 0.94	1.29	n.s.
Visual complexity	4.18 ± 1.28	3.02 ± 1.51	-4.69	*<.001*

Table 4. Behavioural results: mean reaction times (RTs, ms) obtained by the participants in the three familiarization sessions.

		Session 1	*Session 2*	*Session 3*	*Average*
PNT	Nouns	675	628	616	640
	Verbs	719	681	649	683
	Nouns-Verbs	-44	-53	-33	-43
GCST	Nouns	714	662	643	673
	Verbs	640	608	578	609
	Nouns-Verbs	74	54	65	64

Table 5. Stepwise multiple regression analysis on the GCST RTs: standardized beta-coefficients, their corresponding t-values and their associated probability are reported, together with the partial correlation of each predictor with the dependent variable (inverse-transformed RTs in the third familiarization session).

VARIABLES EXCLUDED FROM THE MODEL	Beta	t-value	p	Partial correlation
Number of Letters	-.13	-1.22	.22	-.13
Age of Acquisition	.01	.07	.94	.01
Imageability	-.04	-.36	.71	.04
Stem Frequency	-.13	-1.25	.21	-.14
Saturated model statistics:	r^2 = .04	F[4,82]=.78	p = .53	

Table 6. Stepwise multiple regression analysis on the PNT RTs: standardized Beta coefficients, their corresponding t-values and their associated probability are reported, together with the partial correlation of each predictor with the dependent variable (inverse-transformed RTs in the third familiarization session).

VARIABLES INCLUDED IN THE MODEL	Beta	t-value	p	Partial correlation
Imageability	-.27	-2.64	.01	-.27
VARIABLES EXCLUDED FROM THE MODEL	Beta	t-value	p	Partial correlation
Age of Acquisition	.10	.89	.38	.09
Number of Letters	.04	.36	.72	-.12
Stem frequency	-.04	-.37	.71	-.04
Model statistics: $r^2 = .08$ $F[1,87]=7.01$ $p = .01$				

Table 7. Correlation matrix between the lexical-semantic variables considered. The R *coefficients obtained for the PNT stimuli are reported in normal typeface below the diagonal, while those calculated for the GCST stimuli are reported in italic above the diagonal. Significant values at p<.05 are indicated with an asterisk.*

	Stem frequency	Surface frequency	Letters	Syllables	Age of Acquisition	Imageability
Stem Frequency	1	*.80**	*-.03*	*-.10*	*-.10*	*-.14*
Surface Frequency	.68*	1	*-.04*	*-.14*	*-.18*	*-.12*
Number of Letters	.01	-.13	1	*.84**	*.47**	*-.02*
Number of Syllables	-.06	-.17	.83*	1	*.51**	*-.04*
Age of Acquisition	-.16	-.34*	.17	.18	1	*-.47**
Imageability	-.19	.01	-.23*	-.24*	-.37*	1

Table 8. Brain regions of significant activation for the GCST (statistical threshold= .001 uncorrected; cluster size ≥ 20; Talairach stereotactic coordinates are reported).

°Z-score statistically significant also after the Family-wise Error (FWE) correction.

** Z-score statistically significant also after the False Discovery Rate (FDR) correction.*

Brain regions	x	y	z	Z score	x	y	z	Z score
	Left hemisphere				**Right hemisphere**			
Nouns > baseline								
Middle Frontal gyrus	-46	26	32	3.8*				
	-48	26	36	3.8*				
Inferior Frontal gyrus pars	-48	28	0	4.8*°				
	-48	16	30	4.2*°				
Inferior Frontal gyrus pars Orbitalis	-46	20	-6	4.4*				
	-44	28	-2	4.6*				
Precentral gyrus	-44	4	36	4.9*°				
	-48	4	50	4.2*				
Superior Temporal pole	-52	14	-16	4.7*°				
Inferior Temporal gyrus	-54	-48	-18	4.9*°	56	-40	-18	3.5*
	-52	-54	-20	4.6*				
Inferior Parietal lobule	-28	-68	42	4.4*				
Superior Occipital gyrus	-22	-78	40	4.7*°	24	-80	26	3.4*
	-24	-80	32	4.6*°				
Middle Occipital gyrus	-22	-88	18	4.6*				
	-24	-86	22	4.6*				
Inferior Occipital gyrus	-26	-96	-10	6.0*°	36	-86	-12	5.6*°
	-12	-96	-6	4.6*	24	-100	0	6.5*°
Lingual					24	-90	-12	5.7*°
					28	-92	-12	5.6*°
Calcarine fissure	-14	-92	-4	4.7*°	24	-100	0	6.5*°
Cerebellum	-8	-74	-20	4.8*°	38	-76	-32	5.6*°

Table 8 (follows)

Brain regions	x	y	z	Z score	x	y	z	Z score
	Left hemisphere				Right hemisphere			
Verbs > baseline								
Precentral gyrus	-50	-2	50	3.5*	34	-14	56	3.5*
	-46	-4	38	4.0*				
Supplementary Motor area	-8	8	50	3.7*				
Middle Cingulate gyrus	-2	-40	56	3.4*				
	-4	-8	38	3.2				
Superior Temporal gyrus	-50	-46	24	4.3*				
Middle Temporal pole					48	8	-22	3.9*
Middle Temporal gyrus	-60	-4	-12	4.0*	54	-6	-18	3.2
	-58	-52	-2	4.1*	58	0	-14	3.1
Inferior Temporal gyrus	-60	-54	-10	3.8*	56	-42	-16	3.5*
	-58	-54	-18	3.6*	36	-90	-10	3.4*
Supramarginal gyrus	-58	-46	26	3.8*				
Angular gyrus	-42	-48	30	3.5*				
	-36	-50	34	3.6*				
Lingual gyrus	-22	-100	-14	3.4	26	-94	-14	4.1*
					26	-88	-16	4.0*
Inferior Occipital gyrus					44	-86	-12	3.4*
Calcarine					24	-102	2	3.8*
Cerebellum	-40	-54	-32	5.0*°	36	-72	-30	3.5*
	-38	-82	-22	3.4*	34	-68	-28	3.5*
Hippocampus	-32	-24	-10	3.8*				

Table 8 (end)

Brain regions	x	y	z	Z score	x	y	z	Z score
	Left hemisphere				**Right hemisphere**			
Nouns > Verbs								
Inferior Frontal gyrus pars	-52	24	2	4.4				
	-38	36	18	3.7				
Inferior Frontal gyrus pars Orbitalis	-44	28	-14	3.7				
Inferior Parietal lobule	-46	-46	62	3.2				
Precuneus	-8	-72	62	4.1				
Middle Occipital gyrus	-24	-88	16	3.4				
Superior Occipital gyrus	-18	-80	42	3.2				
Cerebellum	-38	-72	-28	3.3	36	-74	-30	3.7
Verbs > Nouns								
Superior Frontal gyrus	-12	12	54	4.6*				
Precentral gyrus	-26	-18	62	3.8*	18	-30	66	4.0*
	-32	-24	58	3.6*	16	-26	64	3.9*
Supplementary motor area	-6	-12	64	3.2	4	-20	58	4.5*
					12	-8	54	3.7
Middle Cingulum	-4	-38	46	3.4	2	-34	52	3.5
	-2	-40	50	3.4				
Postcentral gyrus					16	-34	64	4.2*
					20	-40	64	4.4*
Paracentral lobule					6	-32	56	3.5
Precuneus					4	-38	56	3.6
					2	-42	56	3.4
Parahippocampal gyrus					16	-2	-16	3.6
Pallidum					22	-4	4	3.4

Table 9. Brain regions of significant activation for the PNT contrasts (statistical threshold= .001 uncorrected; cluster size ≥ 20; Talairach stereotactic coordinates are reported).

°Z-score statistically significant also after the FWE correction.

** Z-score statistically significant also after the FDR correction.*

Brain regions	x	y	z	Z score	x	y	z	Z
	Left hemisphere				Right hemisphere			
Nouns > baseline								
Inferior temporal gyrus					50	-64	-18	5.6*°
Superior Occipital gyrus	-22	-92	34	3.2*				
Inferior Occipital gyrus	-44	-78	-8	6.6*°	36	-92	0	5.0*°
					48	-82	-2	6.6*°
Cerebellum	-38	-54	-28	5.7*°	44	-50	-26	4.5*
					40	-50	-32	5.2*°
Verbs > baseline								
Inferior Frontal gyrus pars triangularis	-54	30	20	3.5*				
	-50	26	32	3.1*				
Inferior Temporal gyrus					52	-66	-12	6.7*°
Cuneus					16	-86	46	3.2*
Superior Occipital gyrus	-24	-88	28	6.1*°	28	-88	28	5.0*°
	-26	-88	24	5.9*°				
Middle Occipital gyrus	-32	-90	16	5.4*°	36	-92	4	6.5*°
	-34	-94	8	5.3*°	34	-88	16	6.2*°
Calcarine	-10	-78	6	4.3*				
Inferior Occipital gyrus	-46	-74	-8	7.4*°	48	-80	-2	7.5*°
	-52	-72	-2	7.3*°	52	-66	-12	6.7*°
Fusiform gyrus	-24	-74	-8	4.6*°				
Lingual gyrus	-8	-74	6	4.3*	10	-58	0	4.0*
	-12	-62	-2	3.5*	38	-46	-32	6.8*°
Cerebellum	-42	-62	-22	7.1*°	40	-64	-22	5.9*°
	-44	-54	-26	6.7				
Hippocampus					22	-32	-4	4.4*
Parahippocampal gyrus	-18	-34	-8	3.8*				

Table 9 (follows)

Brain regions	x	y	z	Z score	x	y	z	Z score
	Left hemisphere				**Right hemisphere**			
Verbs > Nouns								
Inferior Frontal gyrus	-36	22	2	4.0*				
Insula	-32	20	2	3.9*				
Paracentral lobule	-10	-38	72	3.4*				
					8	-36	66	3.4*
Superior Parietal lobule					26	-56	60	3.8*
Precuneus	-12	-46	74	3.3*	10	-42	60	3.6*
	-10	-50	66	3.3*				
Middle Temporal gyrus	-58	-50	6	4.2*	52	-76	8	6.1*°
					52	-66	0	5.7*°
Inferior Temporal gyrus					48	-34	-20	3.5*
Superior Occipital gyrus	-20	-80	28	3.2*	24	-90	34	4.2*
					22	-94	26	3.5*
Middle Occipital gyrus	-50	-72	6	6.0*°	38	-86	6	4.4*
Calcarine	-10	-	-12	3.5*	16	-90	4	4.3*
					12	-92	12	3.4*
Lingual gyrus	-12	-82	-6	3.6*				
	-6	-70	6	3.4*				
Cerebellum	-34	-36	-32	3.7*	44	-44	-28	4.7*°
	-46	-54	-26	3.4*	22	-74	-16	4.4*
Putamen	-28	14	-2	4.0*				
Hippocampus	-14	-2	-14	3.6*				

Table 10. Brain regions showing activation for the verbs-minus-nouns comparison in both the PNT and the GCST (statistical threshold= .05 uncorrected; cluster size ≥ 20; Talairach stereotactic coordinates are reported).

°Z-score statistically significant also after the FWE correction.

** Z-score statistically significant also after the FDR correction.*

Brain regions	x	y	z	Z score	x	y	z	Z score
	Left hemisphere				**Right hemisphere**			
Precentral gyrus	-40	-24	60	4.5*	38	-26	58	4.2*
	-22	-18	62	4.4*				
Supplementary Motor area					4	-8	58	4.0*
Postcentral gyrus	-32	-24	46	4.9*°	26	-46	64	5.0*°
	-38	-34	58	4.6*	16	-30	60	4.4*
Paracentral lobule	-14	-34	74	4.2*	10	-36	64	5.0*°
	-8	-22	58	4.7*				
Superior Parietal lobule	-18	-56	60	4.3*	18	-44	70	4.9*°
					16	-42	64	5.4*°
Precuneus	-14	-44	66	4.3*	10	-42	64	5.1*°
	-12	-40	68	4.3*	6	-40	60	5.2*°
Inferior Parietal lobule					32	-46	56	4.2*
Hippocampus	-14	-4	-16	4.2*				
Amygdala					18	0	-14	4.8*°
Thalamus	-18	-28	10	4.0*				

Table 11. Brain regions showing activation for the verbs-minus-nouns comparison in the PNT and the nouns-minus-verbs comparison in the GCST (statistical threshold= .05 uncorrected; cluster size ≥ 20; Talairach stereotactic coordinates are reported).

°Z-score statistically significant also after the FWE correction.

** Z-score statistically significant also after the FDR correction.*

Brain regions	x	y	z	Z score	x	y	z	Z score
	Left hemisphere				**Right hemisphere**			
Inferior Frontal gyrus pars	-52	32	14	2.9				
	-48	24	22	2.6				
Insula	-30	22	-2	2.6				
Inferior Temporal gyrus	-54	-56	-16	2.6				
	-48	-50	-18	2.3				
Superior Occipital gyrus	-24	-86	28	5.0*°	26	-80	30	3.9*
Middle Occipital gyrus	-26	-88	20	5.2*°	32	-88	14	4.2*
	-28	-94	10	4.0*	38	-74	10	2.8
Cerebellum	-12	-78	-16	4.0*	10	-70	-34	3.9*
	-38	-74	-18	2.8	10	-78	-18	3.6*

APPENDIX A: LIST OF THE STIMULI ENTERING THE GCST

GC = grammatical class; Conj = conjugation; Stem freq = oral stem frequency; Surf freq = oral surface frequency; Let = number of letters; Syl = number of syllables; AoA = Age of acquisition; Imag = imageability.

N	Item		GC	Conj	Stem freq	Surf freq	Let	Syl	AoA	Imag
1	abbracciare	to embrace	verb	1	17	1	11	4	3,1	5,0
2	arrestare	to arrest	verb	1	9	0	9	4	5,0	4,0
3	baciare	to kiss	verb	1	1	1	7	3	2,8	6,1
4	ballare	to dance	verb	1	17	7	7	3	3,1	4,9
5	bombardare	to bomb	verb	1	0	0	10	4	6,1	4,0
6	calcolare	to calculate	verb	1	11	3	9	4	4,8	4,3
7	camminare	to walk	verb	1	18	6	9	4	2,3	5,1
8	cantare	to sing	verb	1	11	4	7	3	2,5	4,5
9	conversare	to converse	verb	1	1	1	10	4	6,4	4,5
10	crollare	to collapse	verb	1	8	2	8	3	5,6	4,2
11	giurare	to swear	verb	1	22	2	7	3	4,9	3,2
12	interrogare	to examine	verb	1	15	2	11	5	5,1	4,7
13	lanciare	to throw	verb	1	22	2	8	3	3,5	4,3
14	massaggiare	to massage	verb	1	0	0	11	4	5,6	4,6
15	nevicare	to snow	verb	1	4	0	8	4	2,9	5,7
16	pattinare	to skate	verb	1	0	0	9	4	4,0	5,3
17	potare	to prune	verb	1	7	0	6	3	6,8	3,7
18	pregare	to pray	verb	1	41	3	7	3	3,5	4,6
19	saltare	to jump	verb	1	22	2	7	3	2,3	4,5
20	salutare	to greet	verb	1	111	9	8	4	1,4	5,1
21	salvare	to save	verb	1	22	9	7	3	4,5	2,6
22	sbadigliare	to yawn	verb	1	1	1	11	4	3,6	5,2
23	scoppiare	to burst	verb	1	9	1	9	3	4,2	4,1
24	soffiare	to puff	verb	1	9	0	8	3	2,7	4,2
25	sparare	to shoot	verb	1	9	2	7	3	4,2	4,9
26	ululare	to howl	verb	1	0	0	7	4	5,2	4,0
27	volare	to fly	verb	1	17	9	6	3	2,4	4,1
28	cadere	to fall	verb	2	62	19	6	3	2,3	4,6
29	correre	to run	verb	2	29	3	7	3	2,5	5,3
30	esplodere	to explode	verb	2	7	2	9	4	5,1	4,5
31	evadere	to escape	verb	2	0	0	7	4	6,6	3,2
32	leggere	to read	verb	2	263	67	7	3	3,4	4,8
33	mordere	to bite	verb	2	0	0	7	3	3,3	5,0
34	nascere	to be born	verb	2	94	7	7	3	3,4	3,6
35	piangere	to cry	verb	2	24	7	8	3	1,9	4,4

36	piovere	to rain	verb	2	10	0	7	3	2,4	5,3
37	raccogliere	to harvest	verb	2	39	6	11	4	3,2	4,0
38	radere	to shave	verb	2	3	0	6	3	6,6	4,5
39	ridere	to laugh	verb	2	41	22	6	3	1,8	5,5
40	scrivere	to write	verb	2	420	57	8	3	3,2	5,0
41	applaudire	to applaud	verb	3	2	2	10	5	4,7	5,1
42	costruire	to build	verb	3	39	16	9	4	3,3	3,9
43	partire	to leave	verb	3	207	62	7	3	3,9	4,2
44	ruggire	to roar	verb	3	0	0	7	3	5,0	4,2
45	starnutire	to sneeze	verb	3	0	0	10	4	4,2	5,0
46	abbraccio	embrace	noun		15	13	9	3	2,7	6,0
47	applauso	applause	noun		10	6	8	4	4,2	4,9
48	arresto	arrest	noun		0	0	7	3	5,6	3,0
49	bacio	kiss	noun		61	19	5	2	1,8	6,0
50	ballo	dance	noun		5	5	5	2	3,0	5,8
51	bombardamento	bombardment	noun		3	2	13	5	6,2	4,5
52	caduta	fall	noun		5	4	6	3	2,7	4,0
53	calcolo	calculation	noun		32	12	7	3	5,8	2,5
54	camminata	walk	noun		0	0	9	4	4,5	4,5
55	canto	song	noun		10	10	5	2	2,6	4,7
56	conversazione	conversation	noun		10	10	13	5	6,9	4,1
57	corsa	run	noun		8	7	5	2	2,8	4,2
58	costruzione	construction	noun		34	27	11	4	3,7	3,9
59	crollo	collapse	noun		2	2	6	2	5,6	4,2
60	esplosione	explosion	noun		3	3	10	4	5,3	5,0
61	evasione	escape	noun		4	4	8	4	6,5	3,0
62	giuramento	oath	noun		8	7	10	4	5,8	2,8
63	interrogazione	interrogation	noun		12	6	15	6	5,8	4,4
64	lancio	throw	noun		0	0	6	2	3,8	3,8
65	lettura	reading	noun		64	54	7	3	4,2	3,4
66	massaggio	massage	noun		0	0	9	3	5,2	5,1
67	morso	bite	noun		5	4	5	2	2,2	4,1
68	nascita	birth	noun		34	33	7	3	3,9	5,3
69	nevicata	snow	noun		14	14	6	3	2,2	6,2
70	partenza	departure	noun		15	15	8	3	3,8	3,2
71	pattinaggio	skating	noun		0	0	11	4	4,5	4,5
72	pianto	crying	noun		1	1	6	2	2,2	4,7
73	pioggia	rain	noun		25	14	7	2	2,4	6,2
74	potatura	pruning	noun		0	0	8	4	7,1	3,8
75	preghiera	prayer	noun		12	8	9	3	3,1	3,1
76	raccolta	harvest	noun		19	17	8	3	4,6	3,0

77	rasatura	shaving	noun	0	0	8	4	6,5	3,8
78	risata	laugh	noun	4	1	6	3	3,5	4,3
79	ruggito	roar	noun	0	0	7	3	4,7	4,2
80	salto	jump	noun	11	9	5	2	2,4	4,0
81	saluto	greeting	noun	41	23	6	3	2,5	4,6
82	salvataggio	rescue	noun	0	0	11	4	5,5	4,2
83	sbadiglio	yawn	noun	0	0	9	3	3,4	5,3
84	scoppio	burst	noun	4	4	7	2	4,8	4,2
85	scrittura	writing	noun	11	10	9	3	3,9	4,1
86	soffio	puff	noun	0	0	6	2	3,5	2,9
87	sparo	shot	noun	0	0	5	2	4,1	4,0
88	starnuto	sneeze	noun	0	0	8	3	4,1	5,4
89	ululato	howl	noun	1	1	7	4	5,4	4,2
90	volo	flight	noun	13	11	4	2	3,2	4,8

APPENDIX B: LIST OF THE STIMULI ENTERING THE PNT.

GC = grammatical class; Conj = conjugation; Stem freq = oral stem frequency; Surf freq = oral surface frequency; Let = number of letters; Syl = number of syllables; AoA = Age of acquisition; Imag = imageability.

N	Item		GC	Conj	Stem freq	Surf freq	Let	Syl	AoA	Imag
1	accarezzare	to caress	verb	1	2	2	11	5	2,7	5,6
2	affogare	to drown	verb	1	1	1	8	4	4,3	4,3
3	affondare	to sink	verb	1	2	2	9	4	5,1	3,9
4	annaffiare	to water	verb	1	0	0	10	4	4,1	4,9
5	atterrare	to land	verb	1	1	1	9	4	5,9	3,9
6	baciare	to kiss	verb	1	1	1	7	3	2,5	5,5
7	brillare	to shine	verb	1	1	1	8	3	4,8	3,6
8	bussare	to knock	verb	1	0	0	7	3	3,4	5,4
9	camminare	to walk	verb	1	18	6	9	4	2,1	5,8
10	decollare	to take off	verb	1	1	1	9	4	6,0	4,4
11	fischiare	to hiss	verb	1	3	1	9	3	3,8	4,5
12	gonfiare	to swell	verb	1	7	0	8	3	4,0	4,4
13	guidare	to guide/drive	verb	1	14	2	7	3	4,6	5,6
14	imbucare	to post	verb	1	6	0	8	4	5,7	3,9
15	lanciare	to launch	verb	1	22	2	8	3	3,2	4,5
16	leccare	to lick	verb	1	0	0	7	3	2,9	4,4
17	legare	to tie	verb	1	40	1	6	3	3,6	4,5
18	marciare	to march	verb	1	4	1	8	3	5,5	4,3
19	nuotare	to swim	verb	1	0	0	7	3	3,9	5,9
20	pattinare	to skate	verb	1	0	0	9	4	4,5	5,2
21	pelare	to peel	verb	1	0	0	6	3	5,0	3,9
22	pregare	to pray	verb	1	41	3	7	3	4,5	5,9
23	salutare	to greet	verb	1	111	9	8	4	1,8	5,4
24	sanguinare	to bleed	verb	1	1	1	10	4	4,1	4,5
25	sbadigliare	to yawn	verb	1	1	1	11	4	3,5	5,7
26	sciare	to ski	verb	1	0	0	6	3	4,4	5,5
27	scivolare	to slip	verb	1	14	8	9	4	2,9	4,5
28	soffiare	to blow	verb	1	9	0	8	3	2,4	5,3
29	sollevare	to raise	verb	1	3	2	9	4	4,4	4,3
30	sparare	to shoot	verb	1	9	2	7	3	4,2	4,3
31	tagliare	to cut	verb	1	39	14	8	3	3,0	5,0
32	volare	to fly	verb	1	17	9	6	3	2,9	4,4
33	bere	to drink	verb	2	18	8	4	2	1,6	5,7
34	cadere	to fall	verb	2	62	19	6	3	1,8	4,3

35	mordere	to bite	verb	2	0	0	7	3	2,6	5,1
36	piangere	to cry	verb	2	24	7	8	3	1,8	5,1
37	raccogliere	to collect	verb	2	39	6	11	4	3,9	4,2
38	ridere	to laugh	verb	2	41	22	6	3	2,3	5,6
39	scendere	to descend	verb	2	44	12	8	3	2,6	4,2
40	scrivere	to write	verb	2	420	57	8	3	3,5	5,6
41	scuotere	to shake	verb	2	0	0	8	3	5,5	3,7
42	spingere	to push	verb	2	13	2	8	3	3,2	4,2
43	ruggire	to roar	verb	3	0	0	7	3	4,2	3,4
44	salire	to go up	verb	3	35	10	6	3	2,9	4,2
45	starnutire	to sneeze	verb	3	0	0	10	4	2,9	4,8
46	ananas	pineapple	noun		1	1	6	3	4,5	6,4
47	arpa	harp	noun		2	2	4	2	5,7	5,5
48	banana	banana	noun		0	0	6	3	2,3	6,3
49	bottiglia	bottle	noun		11	8	9	3	1,9	6,6
50	camion	truck	noun		12	12	6	2	3,1	6,0
51	cammello	camel	noun		0	0	8	3	3,9	5,7
52	candela	candle	noun		0	0	7	3	2,7	6,5
53	cane	dog	noun		59	39	4	2	1,9	6,2
54	canguro	kangaroo	noun		0	0	7	3	3,9	5,6
55	carota	carrot	noun		4	2	6	3	2,9	6,2
56	cavallo	horse	noun		43	37	7	3	2,6	6,2
57	chiesa	church	noun		34	30	6	2	2,9	6,2
58	chitarra	guitar	noun		3	3	8	3	4,3	6,5
59	ciliegia	cherry	noun		0	0	8	3	2,9	6,5
60	clessidra	hourglass	noun		0	0	9	3	6,1	5,9
61	coltello	knife	noun		2	2	8	3	2,3	6,5
62	cravatta	necktie	noun		2	2	8	3	3,9	6,3
63	cucchiaio	spoon	noun		7	7	9	3	2,0	6,5
64	damigiana	demijohn	noun		0	0	9	4	4,9	5,1
65	divano	sofa	noun		36	32	6	3	2,5	6,5
66	elefante	elephant	noun		1	1	8	4	2,7	6,2
67	fionda	sling	noun		0	0	6	2	4,4	5,2
68	fragola	strawberry	noun		0	0	7	3	2,5	6,5
69	giacca	jacket	noun		9	5	6	2	3,3	6,1
70	giraffa	giraffe	noun		0	0	7	3	2,9	5,7
71	guanto	glove	noun		0	0	6	2	2,9	6,3
72	gufo	owl	noun		0	0	4	2	4,1	5,5
73	imbuto	funnel	noun		0	0	6	3	3,8	5,9
74	ippopotamo	hippopotamus	noun		1	1	10	5	4,0	5,7
75	maiale	pig	noun		15	13	6	3	2,5	6,0

76	manette	handcuffs	noun	0	0	7	3	5,1	5,8
77	pappagallo	parrot	noun	2	2	10	4	3,5	5,8
78	pavone	peacock	noun	1	1	6	3	4,5	5,3
79	pinguino	penguin	noun	1	1	8	3	3,3	5,7
80	pipa	pipe	noun	1	1	4	2	3,6	5,9
81	piramide	pyramid	noun	4	3	8	4	4,7	6,1
82	rinoceronte	rhinoceros	noun	0	0	11	5	4,6	5,6
83	scarpa	shoe	noun	17	4	6	2	2,1	6,2
84	scoiattolo	squirrel	noun	0	0	10	4	2,9	5,7
85	stivale	boot	noun	3	0	7	3	3,5	5,8
86	tamburo	drum	noun	0	0	7	3	3,3	6,2
87	tavolo	table	noun	59	34	6	3	2,1	6,4
88	topo	mouse	noun	3	2	4	2	2,6	5,8
89	zebra	zebra	noun	0	0	5	2	3,6	5,8
90	zucca	pumpkin	noun	5	2	5	2	4,8	5,5

5 CONCLUSIONS

There is wide linguistic evidence showing that words combine in grammatical classes according to their distributional properties in natural sentences. There is little doubt that nouns and verbs have a privileged status among these classes, arguably reflecting the basic syntactic-communicational dichotomy between reference/denotation (i.e., nouns singled out a specific set of objects) and predication (i.e., verbs specify an action or a state of being of this class of objects; see Chapter 1).

This led several psychologists and cognitive neuroscientists to investigate whether/how nouns and verbs are differently represented and processed in the human linguistic system. This effort in understanding the mental representation of grammatical classes was initially enhanced by the observation of brain-damaged patients suffering from disproportionate impairment of either noun or verb retrieval (e.g., Holmes et al., 1971). Since this seminal work, several other brain-damaged patients have been described who showed noun-verb dissociation (e.g., Zingeser and Berndt, 1988, Caramazza and Hillis, 1991, Bird et al., 2000, Luzzatti et al., 2002) and different cognitive *loci* of impairment have been indicated as responsible for the emergence of this phenomenon (e.g., Rapp and Caramazza, 2002, Bird et al., 2000, Crepaldi et al., 2006).

Indeed, there is strong evidence suggesting that different functional damages may cause the dissociation in different patients; this hypothesis has been tested in Chapter 2, where the spontaneous speech of seven aphasic patients showing a predominant noun- or verb-impairment in picture naming has been analyzed in a single-case series study. Non-fluent verb-impaired patients showed a reduced verb-type production in their narratives; the consistency of their verb-specific damage across single word retrieval and spontaneous speech and the association of this impairment with a reduced production of closed-class words suggest that these patients suffer from a central, lemma-level damage. This is further confirmed by the brain lesion characterizing one of these patients, which involves the whole left peri-sylvian cortex and the underlying white matter; this suggests the emergence of right hemisphere language abilities, which are known to be lacking of syntactic and lexical-syntactic competence, i.e., of a lemma level (e.g., Coltheart, 2000). By contrast, fluent verb-impaired patients do not show a lower-than-normal production of verbs in their spontaneous speech (neither in terms of total productivity – the token count – nor in terms of lexical diversity – the type and root count). This has been interpreted as a consequence of a functional damage involving the activation of lexemes by the corresponding lemmas; therefore, these patients have no problems at producing verbs in syntactically rich linguistic contexts, like spontaneous speech, that highly stimulate the lemma level enhancing the activation flowing down to the lexeme level. Finally, fluent noun-impaired patients do not show a homogeneous pattern of noun production in their narratives, further suggesting the presence of different functional damages underlying noun-verb dissociation.

Notwithstanding the great deal of neuropsychological evidence on the noun-verb dissociation, the role of grammatical class in psycholinguistic phenomena has been a largely unaddressed issue, the different representation of nouns and verbs being either indirectly derived from other source of evidence (e.g., Levelt et al., 1999) or neglected (e.g., Forster et al., 1987, Meunier and Marslen-Wilson, 2004). A series of psycholinguistic experiments has been presented in Chapter 3 where the grammatical class of primes and probes has been manipulated in order to investigate the (possibly) separate representation of nouns and verbs at the morphological and semantic level. Cross-class morphological priming, i.e., the facilitation between morphologically related nouns and verbs, e.g. *partire*, to leave, and *partenza*, departure, consistently arises across different Stimulus Onset Asynchronies (SOA, the time interval between the presentation of the prime and the probe) and irrespective of whether nouns prime verbs or verbs prime nouns. This evidence strongly suggests that morphological roots subserving the construction of both nouns and verbs (*part-*, in the example given above) have a unique representation, which is unmarked for grammatical class: this representation is called upon both when nouns and verbs are read by the subjects. Cross-class morphological priming also emerges when the prime is presented only 100 ms before the presentation of the probe: this indicates that the unitary grammatical-class-free representation of the root is already addressed after 100 ms, i.e., since the early steps of the visual word recognition process. Considering our results together with those reported by previous studies on morphological priming (e.g., Rastle et al., 2003), we have argued that there is a very early (likely pre-lexical) morphological processing system that single out morphemes during visual word recognition independently from syntactic-semantic factors, like grammatical class (as demonstrated by the experiments carried out in this thesis) and semantic transparency (as shown by, e.g., Rastle et al., 2004).

In noun-verb pairs like *applauso*, applause, and *applaudire*, to applaud, the morphological relatedness implies by definition semantic relatedness. In order to disentangle the genuine morphological effect from this concurrent semantic effect, and in order to investigate the noun-verb dichotomy also from a semantic point of view, cross-class semantic priming has been also assessed (e.g, *applauso-ammirare*, to admire, and *applaudire-teatro*, theatre). Semantically related nouns and verbs facilitate each other when the SOA is set to 300 ms; by contrast, when the SOA was as brief as 100 ms, priming effect emerged only when nouns were used as primes and verbs as probes, but not vice versa. We interpreted this effect as due to the grammatical class of the prime. When the visual word recognition system receives a verb in input, a different processing is triggered as compared to when a noun is presented, according to which the word lexical-syntactic properties become more relevant than their semantic characteristics; this would make the semantic relationship between primes and probes poorly relevant and would prevent semantic priming from emerging. However, the grammatical-class-of-the-prime hypothesis does not explain the results emerged at the 300-ms SOA: in this condition, in fact, priming is observed also when verbs prime related nouns (e.g., *baciare-amore*, to kiss-love$_N$). With such an SOA though, semantic facilitation is not observed in the verb-verb condition (e.g., *baciare-amare*, to kiss-to love). Arguably, this lack of semantic priming among verbs can be traced back to the structure of the semantic space framing verb concepts: this is in fact emptier and less hierarchically-structured than that hosting noun concepts, due to the fact that the semantic representations underlying verbs share few semantic features even when they appear to be strongly related.

As the functional difference between the two grammatical classes received further substantiation, an increasing effort was put on determining whether different neural circuits are responsible for noun and verb processing. Nevertheless, this issue has been investigated in fMRI and PET studies with a number of different experimental tasks and baselines, sometimes not taking into the proper consideration the functional levels of analysis entailed by the experimental task-baseline comparison. This has resulted in a body of rather inconsistent evidence, as shown in Chapter 1. In line with these considerations, we carried out an fMRI experiment (Chapter 4) in which a factorial design was adopted with two different tasks (picture naming task, PNT, and grammatical class switching task, GCST) tapping on the same cognitive process, i.e., lexical-semantic processing; this experimental design allowed us to distinguish between task-dependent and task-independent activations specific for either nouns or verbs. No brain area was consistently activated by lexical-semantic processing of nouns in both the PNT and the GCST; this is arguably due to the fact than nouns included in the two tasks had different degrees of imageability (i.e., highly imageable in the PNT as they had to be pictured, poorly imageable in the GCST as they had to be matched with verbs). By contrast, verb processing reliably activated across tasks a fronto-parietal network including the pre-central gyrus bilaterally, the right supplementary motor area and, bilaterally, the post-central gyrus, the posterior parietal gyrus, the paracentral lobule and the precuneus. This network has been convincingly demonstrated to underlie the formation of new motor representations in observational learning (Frey and Gerry, 2006), the visuo-motor integration and the planning of object-related action (Grefkes and Fink, 2005); hence, our results suggest that verb lexical-semantic representations are strictly connected with neural networks responsible for (visuo-)spatial action-oriented processing. Finally, a grammatical-class-by-task interaction analysis revealed that the left inferior frontal gyrus (LIFG), which has been frequently reported as specific for verbs (e.g., Chao et al., 2000, Shapiro et al., 2005), is mostly activated by verbs in the PNT, but by nouns in the GCST. This interaction between grammatical class and task is mirrored in the analysis of the reaction times: indeed, verbs elicited slower responses than nouns in the PNT, whereas nouns elicited slower responses than verbs in the GCST. In other words, the LIFG turned out to be associated in both tasks with the grammatical class eliciting the slowest reaction times. This suggests that the LIFG does not underlie the processing of either grammatical class *per se*; rather, its activation reflects the processing load determined by the task demand, which may vary according to the grammatical class being processed (in this case, verbs were more demanding than nouns in the PNT, while nouns were more demanding than verbs in the GCST).

To sum up, the experiments reported in the present thesis allow us drawing some conclusions on the mental representation of nouns and verbs, and in particular on those aspects of this issue that have been shown to be still open to debate in Chapter 1:

i. At which cognitive level nouns and verbs are represented separately in the mental linguistic system?
ii. Do all brain-damaged patients showing disproportionate impairment of either nouns or verbs suffer from the same functional impairment?

iii. Are nouns and verbs processed by neural circuits that are implemented in different brain regions?

For what concerns the first issue, the neuropsychological and psycholinguistic evidence presented in this work indicates that the grammatical class of words is represented at a central, lexical-syntactic level of representation (i.e., the *lemma level*, see Levelt et al., 1999). The verb-impaired non-fluent patients included in this study suffer from lemma-level impairments, as revealed by the analysis of their spontaneous speech (Chapter 2); hence, a separate representation of nouns and verbs at this level must be assumed. By contrast, no dissociated patient unequivocally showed a lexical-phonological damage (*lexeme level,* Levelt et al., 1999); this implies that a separate representation of nouns and verbs at this level is not required in order for the model to be able to capture the behaviour of all aphasic patients included in this study. Symmetrically, the priming experiments reported in Chapter 3 have shown the existence of an early morphological level of analysis where grammatical class is not represented, i.e., morphological roots subserving the formation of both nouns and verbs (e.g., *part-* in *partire*, to leave, and *partenza*, departure) have a unique representation, which is free from any mark for grammatical class. This further suggests that grammatical class is represented at more central, relatively later stages of lexical processing.

The analysis of the spontaneous speech of verb- and noun-impaired aphasic patients has given new and strong evidence that different functional damages may underlie the emergence of the noun-verb dissociation. This clearly calls for a fine-grained analysis of the performance of dissociated patients: any rehabilitation program aiming at the recovery of the noun- or verb-specific lexical impairment must take into account the functional damage that have caused the dissociation, and must be particularly focused at the cognitive level which is specifically impaired (i.e., the lemma level vs. the lemma-lexeme interface).

Finally, the present work has contributed to clarify the intricate picture of the neural basis of noun and verb processing as emerging from the previous literature. This has been done by showing that:

i. the experimental task and baseline used to investigate this issue crucially contribute to the set of brain areas found to be associated with either grammatical class
ii. factorial designs using two different tasks tapping on a same cognitive process may be useful to let emerge brain areas that are *consistently* activated by a specific cognitive process
iii. lexical-semantic processing of verbs highly activates brain areas crucially involved in (visuo-)spatial action-oriented processing
iv. the LIFG is likely to reflect task demand rather than being specific for either grammatical class *per se*.

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