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Grammatical categories and semantic distinctions: from linguistics to neuroscience

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ABSTRACT

In the present paper, the results of two functional resonance imaging studies on the noun/verb distinction and the telic/atelic distinction are reported and discussed in order to provide an updated evaluation of the way linguistics and neuroscience can feed each other. These results show that brain processing of the noun/verb distinction is related to the representation of verb and noun as graded multifactorial categories, and that verb processing and event knowledge in a verb-selective brain region are specifically related to the representation of telicity.

KEYWORDS: grammatical categories, neuroimaging, semantics, telicity.

1. Introduction.
Language and cognition. The linguistic categorization

Human languages offer a unique opportunity to study how distinct cognitive functions correlate with different patterns of human brain activity. Language, in fact, is a cognitive tool, in so far as it communicates the way in which we represent and categorize the world (e.g., events, objects, places, abstract notions, emotions, etc.). Language does not function as a mirror of what we experience in everyday life, but as an autonomous system of classification and, therefore, of knowledge. If language encoded a fixed image of reality rather than the structures in which human beings represent and organize the world in historically determined cultures, identical categories would apply to all languages. But this is not true. The noetic *continuum* raises an infinite number of possible interpretations and categorizations. Each language – each speaker, we could even say – makes its own cuts in a distinctive way. Even the categories of time and number, which speakers of languages like Italian and English might suppose to be universal, actually vary across languages. In some American Indian languages, for instance, the category of time lacks any

grammatical coding (Whorf, 1956): «the Hopi language is seen to contain no words, grammatical forms, constructions or expressions that refer directly to what we call 'time', or to past, present or future» (Whorf, 1956: 57). Those languages, instead, express the distance of events from the speaker, irrespective of whether events are distant in time or space: what happened yesterday (distance in time) and what happens now in a distant place (distance in space) have the same coding. Similarly, in a very early stage of Indo-European verbal system the grammatical coding of time was lacking. At that stage, Indo-European expressed the relationship between either verb and person or verb and voice, but it did not express the relationship between verb and time. Verb system was, instead, organized around the distinction between process (encoded by the injunctive) and state (encoded by the perfect: Lazzeroni, 1980, 1997; Di Giovine, 1990-1996; Romagno, 2005a). Futhermore, in languages like Ancient Greek, which uses the dual form, the notions of 'two' and 'more than one' belong to distinct categories; and the notion of 'two' might in turn be split into two subcategories, depending on whether a natural (e.g., two eyes) or an accidental and temporary (e.g., two enemies) dual is expressed (Plank, 1989).

The arbitrariness of linguistic form, that is its being independent of the factual reality, is even clearer in the organization of lexicon, in which the number of examples is extremely large (see Berlin & Kay, 1969, to mention only an example).

Are we able to analyze the linguistic classification of experiences and concepts by disentangling what is socioculturally determined and, therefore, dependent on historical accidents, from what is, instead, neurobiologically dependent and, therefore, universal?

Neuroscience, and especially functional magnetic resonance imaging (fMRI) methodologies, as they investigate the correlation between patterns of brain activity and cognitive processes, help us address this question[1]. Neuroscience, in its turn, benefits from linguistics. As mentioned above, in fact, the investigation of principles underlying the organization and change of language systems leads to exploring cognitive processes. Linguistic categorization relies on a fine-grained selection of features shared by certain items of interest: on the basis of those features, speakers classify either the extralinguistic or the linguistic objects (Taylor, 1995; Croft & Cruse, 2004;

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[1] On the interaction between cognitive science and neuroscience (with special regard to learning and memory), from an alternative perspective, see GALLISTAL & KING (2010).

Bybee & Slobin, 1982). In conclusion, linguistics provides neuroscientific investigation with representative results of specific cognitive processes, and neuroscience, on the other hand, offers a unique opportunity to investigate how linguistic distinctions are captured in the brain and, therefore, verify whether they rely on universal principles.

2. *Concepts and grammatical categories: The Noun/Verb continuum*

Verbs and nouns represent primary building blocks to convey concepts (e.g., actions and objects, respectively) and fundamental units for morphosyntactic operations (Sapir, 1921; Marantz, 1984; Hopper & Thompson, 1984a; Croft, 1991; Anderson, 1997; Vogel & Comrie, 2000; Baker, 2003, among many others). Verbs and nouns are identified on the basis of formal (morphosyntactic) features. For instance, in languages like Italian or English, in strings such as "*it exists*" and "*he runs*", we are able to classify both "*exists*" and "*runs*" as verbs, even if existing refers to a condition of the subject, whereas running refers to an action performed by the subject; analogously, in strings like "*the table*" and "*the destruction*", we classify both "*table*" and "*destruction*" as nouns, even if the former denotes a physical object, whereas the latter denotes an event[2]. Four or five year old children are even able to assign grammatical categories to pseudowords, in the appropriate syntactic context, and, then, to produce the correct morphological marker, like in "*he zibbed*" or "*two wugs*" (Gleason, 1958). The categories of verb and noun are, therefore, formally discrete, in so far as they are encoded by clear-cut linguistic units[3].

However, formal grounds not only are language-specific and, therefore, differ from language to language, but may also vary in the way they apply to different members of the same category within languages: English progressive form, for instance, is used in conjuction with verbs denoting dynamic events like *to run, to walk* and *to talk*, but not with verbs denoting states such as *to contain, to possess* and *to exist:* *"*it is existing*"* vs. "*he is running*".

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[2] On the denotation of proper names and common nouns, and on the semantic theorizing on nouns (and verbs) as denoting «sets» (or «properties»), see PARTEE (1987), REINHART (1997), WINTER (1997), CHIERCHIA (1998), ENGELHARDT (2000), DAVIDSON (1967).

[3] On isolating languages, and on the blurred boundaries between grammatical categories, see COMRIE (1989: 42 f.), AARTS (2004), EVANS & OSADA (2005), SASSE (2001), HOPPER & THOMPSON (1984), among many others (see below in the main text).

Moreover, verbs and nouns not only show distinct morphosyntactic behaviours, but also differ on semantic grounds. Verbs typically denote events (e.g., walking, eating), while nouns typically denote entities (e.g., table, dog). But verbs may also refer to states (staying) or relations (belonging), and nouns may also refer to events (excursion) or conditions (temperature). The categories of verb and noun – like most of the linguistic categories – in fact, are semantically graded. The relationship between noetic *continuum* and discrete linguistic forms ultimately determines the variation in how morphosyntax maps into the two categories (see Simone, 2008; Ramat, 2005; Evans & Osada, 2005; Aarts, 2004; Sasse, 2001; Vogel & Comrie, 2000; Borsley, 2000; Langacker, 1987; Hopper & Thompson, 1985, 1984a,b; Givón, 1984; Ross, 1972, among many others). It is possible to identify central (prototypical) members of each category, both within and across languages. They show a cluster of properties, shared by other category members in different degrees. Prototypical verbs are agentive dynamic active verbs, with a specified endpoint or outcome, carrying out the function of predication; prototypical nouns denote concrete three-dimensional individualized entities (Lyons's first-order entities: Lyons, 1977) and carry out the function of reference. Thus, verbs like *to murder* and *to build* are the best candidates for prototypical verbs; nouns like *dog* and *table* are the best candidates for prototypical nouns. Table 1 summarizes the basic prototypical properties of the two categories[4]:

	Verb	Noun
morphosyntactic versatility	+	−
semantic class	dynamic event	"first-order" entities
time stability	−	+
existence in space	transitory	persistent
valency	≥ 1 (relational)	0 (non relational)
function	predication	reference

Table 1. *Prototypical features of nouns and verbs*

In conclusion, the categories of verb and noun, identified on the basis of language-specific morphosyntactic features, correspond to a cluster of semantic and functional properties determining the complex mapping relationships between grammar and different dimensions of meaning.

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[4] For a discussion of further verb and noun features, which specifically apply to morphosyntax and pragmatics, see SIMONE (2008), RAMAT (2005), MALCHUKOV (2004).

The picture drawn here raises several questions at the interface between linguistics and neuroscience. Some of those questions have been addressed by prior studies, but an exhaustive account of noun and verb processing in the brain is still conspicuously lacking.

First and foremost, one might ask whether we are able to identify the neural correlates of nouns and verbs and, therefore, establish a neurobiological foundation for the two linguistic categories (Goodlass *et al.*, 1966; Luria & Tsvetkova, 1967; Miceli *et al.*, 1984; McCarthy & Warrington, 1985; Shapiro & Caramazza, 2003a,b; Perani *et al.*, 1999; Shapiro *et al.*, 2006; Bedny *et al.*, 2008, among others). This would lead to isolating the universal components of principles underlying the organization of concepts in distinct grammatical categories, and allow us to analyze those principles separately from sociocultural factors. However, it also raises a series of further questions. What is the role of single noun and verb properties in determining distinct neural responses? How does morphosyntax interact with specific semantic and functional features of the two categories? Are we able to establish a hierarchic relationship between the formal and the semantic ground in brain processing of nouns and verbs? And also to assign distinct weights to semantic properties?[5]

Another open question regards the possible direct association of prototypical semantic features of nouns and verbs with the corresponding morphosyntactic category. Without excluding, in fact, that as soon as we recognize a given phonetic string as a verb or noun on the basis of morphosyntax, we retrieve the whole category of verb or noun and, therefore, the cluster of semantic and functional properties defining the category associated with the given morphosyntactic template, we are not able to disentangle the role of formal features from that of semantic and functional features in modulating neural responses to verbs and nouns.

A first possible answer to the last question comes from a study on a patient with Semantic Dementia (for different kinds of evidence from the same patient, see Romagno *et al.*, 2010, Papagno *et al.*, 2009). Patient MC presented with a severe impairment in accessing word meaning and retrieving lexical items. Both her inferential and referential abilities, governing the mapping relationship between words and extralinguistic entities (Marconi, 1997) were seriously damaged. She was unable to establish the meaning of

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[5] On a multiplanar organization of graded linguistic categories and on diverse roles of prototypical properties in language change, see Lazzeroni (forthcoming).

even common and highly frequent Italian words such as *mucca* "cow" and *nuotare* "to swim", as well as to name objects and events, either in response to a stimulus (e.g., a linguistic or visual cue) or in spontaneous speech. MC's semantic deficit affected both the categories of verb and noun to the same degree and independently of concreteness and animacy.

The aim of the study was to assess whether the patient retained the category specific morphosyntactic information, despite her severe impairment in accessing the meaning of words. To this end, the patient was tested via a sentence completion task including nouns and verbs. She was provided with written sentences (also read aloud by the examiner), like «*la . . . (miagola/ fragola) è il mio frutto preferito*» "the . . . ([he] meows/strawberry) is my favourite fruit", «*è difficile piantare un . . . (chiodo/parlo) nel muro*» "it is difficult driving a ... (nail/[I] talk) into the wall", and asked to complete the sentence by choosing between the two words written in parenthesis. The two alternatives corresponded to distinct grammatical categories (verb vs. noun). Each pair consisted of formally equivalent words, as nouns and verbs had the same number of syllables and, specifically, the same ending (e.g., «*miagol-a*» / «*fragol-a*»), in order to rule out that the patient's response was triggered by inflectional markers recognized as more verbal or nominal respectively. The patient's responses were 100% correct. The observation that MC was not able to access the semantic knowledge of all the target items used in the grammatical category distinction task allows us to suppose that the information governing the processing of nouns and verbs in mutually exclusive morphosyntactic contexts is separately stored and accessible from word meaning.

The results of this study provide a first hint of a dissociation between verb/noun specific morphosyntactic knowledge and semantic knowledge, and reveal a need for disentangling the role of formal features from that of semantic and functional features in brain processing of nouns and verbs.

Selective deficits in processing either verbs or nouns have long been reported (Goodlass *et al.*, 1966; Luria & Tsvetkova, 1967; McCarthy & Warrington, 1985; Caramazza & Hillis, 1991; Shapiro & Caramazza, 2003a, b; Laiacona & Caramazza, 2004), and evidence of a general pattern of correspondences between brain lesions and category specific deficits have been provided by neuropsychological studies (Miceli *et al.*, 1984; Damasio & Tranel, 1993; Daniele *et al.*, 1994; Silveri & Di Betta, 1997; Cappa *et al.*, 1998; Shapiro *et al.*, 2000; Shapiro & Caramazza, 2003a). Nonetheless, it still remains unclear whether patients' impairments are specifically morphosyntactic in nature, or more reflective of difficulties in accessing aspects of

word meaning, like perceptual properties of objects denoted by nouns, or semantic features typically associated with verbs, such as dynamicity.

Several studies on unimpaired brain, and especially functional neuro-imaging studies, which have investigated the representation of nouns and verbs in the brain, have revealed regions selectively engaged in verb process-ing (Willms *et al.*, 2011; Bedny *et al.*, 2011; Bedny *et al.*, 2008; Shapiro *et al.*, 2006; Yokoyama *et al.*, 2006; Kable *et al.*, 2005; Perani *et al.*, 1999). However, converging evidence of neuroanatomical correlates of the noun/verb distinction is conspicuously lacking, which is presumably related to differences in tasks and/or stimuli across studies (Crepaldi *et al.*, 2011; Vi-gliocco *et al.*, 2011). The most robust and consistent finding across studies, tasks and languages is a verb selectivity of the left posterior lateral tempo-ral cortex (PLTC), including the posterior middle temporal gyrus (pMTG) (Warburton *et al.*, 1996; Perani *et al.*, 1999; Davis *et al.*, 2004; Kable *et al.*, 2005; Bedny & Thompson-Schill, 2006; Shapiro *et al.*, 2006; Yokoyama *et al.*, 2006; Bedny *et al.*, 2008; Tyler *et al.*, 2008; Willms *et al.*, 2011). None-theless, the precise role of the multiple and anatomical distinct regions in the PLTC, which show greater activation for verbs relative to nouns, remains unclear. In particular, it still has to be defined whether these regions respond preferentially to the grammatical category of verb, as established on formal grounds, or rather to functional, semantic or sensorimotor features tipically associated with verbs (Wallentin *et al.*, 2011; Kemmerer *et al.*, 2010; Tyler *et al.*, 2008, 2004; Kable *et al.*, 2005; Bedny *et al.*, 2011, 2008; Rodríguez-Ferreiro *et al.*, 2011; Yu *et al.*, 2011).

Most of these prior functional neuroimaging studies have been limited, in that they fail to distinguish between the grammatical categories of verb and noun, as established on the basis of language specific morphosyntactic features, and prototypical semantic properties of verbs and nouns. They have generally contrasted action verbs with object nouns, leaving, therefore, un-known whether verb selectivity relies on morphosyntactic, semantic and/or functional properties (Vigliocco *et al.*, 2011).

Here we report the results of a recent study that investigated the neuro-anatomical correlates of the noun/verb distinction by disentangling gram-matical category specific morphosyntactic information from prototypical semantic features of verbs and nouns (for a complete description of the study, see Peelen *et al.*, 2012, in press). To this purpose, an fMRI block de-sign was used to identify patterns of neural response following processing of semantically prototypical and non-prototypical verbs and nouns, presented

in the morphosyntactically unambiguous contexts of short phrases, like *she walks, he destroys, it includes* and *the table, the destruction, the identity*. Specifically, the study assessed whether differences in dynamicity between previously-used verbs (*to jump* or *to think*) and nouns (*table* or *idea*) modulate brain regions found to be selectively involved in verb processing. In a 2x2 factorial design, we orthogonally manipulated degree of dynamicity and grammatical category, to thus compare four main conditions of interest: dynamic and non-dynamic verbs (*to flow* vs. *to contain*), dynamic and non-dynamic nouns (*the fight* vs. *the identity*). Dynamic verbs denoted dynamic activities unfolding over time and space, such as *to walk* and *to flow*, whereas non-dynamic verbs denoted states or conditions represented above time and space, such as *to exist* and *to contain*. Event and state nouns paralleled verb semantics, as they denote dynamic events, like *the destruction* and *the excursion*, or states and conditions, like *the existence* and *the temperature*. Typical action verb (e.g., *to jump*) and object noun (e.g., *the table*) conditions were also included, to localize the verb selective regions.

To control for the confounding of specific grammatical and semantic factors in verb and noun processing, the study was divided into two experiments, which, otherwise identical, differed in the stimulus material used.

In the first experiment, all event and state verb phrases had an animate subject (*he* or *she:* e.g., *she chases* and *he believes*). Selecting prototypical states could be taken to exclude a dynamic interpretation of them. Nevertheless, it could be argued that an animate subject automatically leads us to understand states as active events, thus resulting in common patterns of cortical activation between state and event verbs. To investigate this possibility, in the second experiment we used event and state verb phrases with inanimate subject, like *it flows* and *it costs*.

To disentangle grammatical category from semantics, both the experiments included event and state nouns semantically comparable to verbs. The first experiment comprised trials with event and state nouns sharing a verbal root, such as *attack* and *possession*. We controlled for the confounding of noun morphological complexity, as we included both nouns derived by a suffix, like *destruction*, and unsuffixed nouns, like *attack*, and all the stimuli were matched for word length. However, one could again argue that processing nouns that share a verbal root automatically retrieves verbs and, therefore, recruits verb-selective cortical regions. To exclude this possibility, in the second experiment, we used only underived event and state nouns with no corresponding verbs, like *excursion* and *temperature*. Stimuli for action

verbs and object nouns, used to localize regions of interest, were identical for the two experiments.

For both experiments, stimuli consisted of twenty Italian short phrases per condition, such as *egli cammina* "he walks" and *la temperatura* "the temperature". The phrases were matched for cumulative and form frequency (Bertinetto *et al.*, 1995), word length in letters, animacy of verb subject (only animate subjects in the first experiment, only inanimate subjects in the second), grammatical gender of nouns and pronouns that preceded verbs, number of core arguments of verbs: on this score, we included both one-argument verbs, such as *to walk*, and two-argument verbs, such as *to build*, matched across conditions. Stimuli were also controlled for age of acquisition, familiarity, imageability and concreteness. To this end, all phrases were rated on these variables on a 1-7 points scale (Bates *et al.*, 2001) by two distinct groups of healthy native Italian volunteers (24 volunteers for the phrases used in the first experiment; 42 for those used in the second). Ratings were, then, normalized and included as regressors of no interest in the fMRI analysis.

The twenty-seven healthy right-handed native Italian volunteers who participated in the study (fifteen for the first experiment and twelve for the second) performed a delayed match-to-sample task[6]. They read three short phrases presented sequentially for 1.5 seconds, each separated by 0.5 seconds; after a 1.5-second interval, a probe phrase, of the same type of the previous three, was presented. Hence, each block consisted of four short phrases of one of the six conditions, occurring in random order. Participants were asked to answer whether the probe phrase was identical to one of the three preceeding phrases, by pressing a button. The matching rate was set at 50% (for further details on materials and methods, see Peelen *et al.*, 2012, in press).

In the present discussion we will focus on two main results of the study, which are of particular interest to linguists and provide neurobiological evidence on the long-debated question of the noun/verb *continuum*.

Four brain regions in the left hemisphere have shown an overall greater activation for verbs compared with nouns, independently of semantic distinction: posterior middle temporal gyrus (pMTG), anterior middle temporal gyrus/superior temporal sulcus (aMTG/STS), inferior frontal gyrus

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[6] In order to rule out morphosyntactic processing needed for the correct production of word forms as a cause of neural response to verbs and nouns, we used a simple memory task that did not involve morphosyntactic processing.

(IFG), middle frontal gyrus (MFG). All these regions, identified by their preference for action verbs over object nouns, also responded selectively to dynamic and non-dynamic verbs when contrasted with dynamic and non-dynamic nouns (e.g., *egli corre* "he runs" vs. *la corsa* "the run", as well as *lei manca* "she lacks" vs. *la mancanza* "the lack"). Among these verb-selective regions:

1) the posterior temporal region, namely pMTG responded more to dynamic nouns than to other noun categories;
2) the more anterior temporal region, namely aMTG/STS gave a stronger response to non-dynamic (i.e., state) verbs relative to dynamic verbs.

Dynamic nouns denoting activities or events, such as *inseguimento* "[the] chase" and *lotta* "[the] fight", elicited a greater pMTG response than other nouns, and showed a similar pattern of activation to verbs. Therefore, nouns that have more verb prototypical semantic properties are associated with a stronger activity in a verb-selective area, relative to state nouns like *possesso* "possession" or *temperatura* "[the] temperature" and object nouns like *tavolo* "[the] table" or *lampada* "[the] lamp". Less prototypical members of noun category as established on semantic grounds are neurally distinct from more prototypical nouns, and show a verb-like pattern of response. Therefore, the semantic variables manipulated in the present study played an important role in modulating neural response to nouns, independently of formal distinctions: all nouns, in fact, were unambiguously encoded by nominal (as opposed to verbal) morphosyntactic markers (e.g., "*il tavolo*" "the table" vs. "*egli cammina*" "he walks"). We are also able to identify a gradient of responses to noun stimuli, with activity/event nouns eliciting greater response than state and object nouns, and state nouns, in turn, eliciting greater response than object nouns.

To summarize, verb-like nouns gave an overall stronger pMTG activation than object nouns. That is, nouns sharing semantic and functional properties with verbs, either more or less prototypical, are neurally distinguishable from prototypical nouns denoting concrete three-dimensional individualized entities («ultra-nomi» "ultra-nouns" or «nomi puri» "pure nouns", in Simone's terms: Simone, 2000), and show a verb-like pattern of response. This applies to either activity/event and state nouns that had a shared root with a verb, such as *la distruzione* "the destruction" and *il possesso* "the possession", or activity/event and state nouns that do not have a shared root with a verb, such as *la rissa* "the fight" and *il nesso* "the link". Thus, independently of the formal structure of words, dynamicity is not the

sole feature affecting pMTG response to nouns. Existence in space and time stability, in fact, correlate with dynamicity, as dynamic events are typically transitory in space and unstable in time, whereas states are typically persistent in space and stable in time. Moreover, valency and predication, which are common to events and states, may have also played a role in modulating pMTG responses to verb-like nouns as compared to object nouns. Relationality and the related ability to carry a predicative function, indeed, depend on the idiosyncratic representation of word meaning, independently of dynamicity and time/space stability. As we have shown above, predication is a prototypical verb property as opposed to reference, which is prototypical for nouns. In their prototypical representation, verbs predicate something about someone or something, whereas nouns only refer to an extralinguistic entity (Simone, 2008; Ramat, 2005, among others). Therefore, predication is relational, reference is not. In so far as an argument structure is entailed, a predicative function is involved: in "Mary is building a dollhouse", for instance, the verb establishes such a relation between a given action and the involved arguments (the actor and the undergoer), that we know that Mary is performing an action and the dollhouse is undergoing a change of state (from the state of non-existence to the state of existence). The nouns *Mary* and *dollhouse*, instead, are not relational, as they do not predicate anything about anything else, but rather refer to certain entities. The activity/event and state nouns used in the experiments described here may carry out the function of predication, as both, for example, *distruzione* "destruction" and *possesso* "possession" entail (at least) two participants, despite differences in what they denote (action vs. state)[7].

In conclusion, the neural response to nouns in a verb-selective brain region such as the left pMTG depends on whether nouns participate of prototypical semantic and functional features of verbs and, therefore, provides evidence for a graded representation of the categories of verb and noun and confirms the results of typological investigations on linguistic data (Aarts, 2004; Evans & Osada, 2005; Sasse, 2001; Hopper & Thompson, 1984a,b; Ross, 1972, among many others: see above). Moreover, the results of this

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[7] I just wish to mention here that the function of predication is not the default function of nouns, including verb-like nouns: activity/event and state nouns such as *destruction* and *arrival* or *merit* and *equivalence* may also be considered as "objects", thus carrying the function of reference, similar to nouns such as *John* and *table*. In this case, the semantic (and pragmatic) context disambiguates. Predication, instead, is the default function of verbs, and the only function of verbs in the finite forms (on infinitives and participles, see Noonan, 1985; Givón, 1990; Ramat, 2002).

study lead us to establish a hierarchy of prototypical verb features which are critical for nouns to be processed in a more similar way to verbs than to prototypical nouns. Dynamicity plays a dominant role in assessing the neural verbiness of nouns: in fact, left pMTG response to dynamic nouns was stronger relative to non-dynamic (state) nouns, and more comparable to responses to verbs in the same area.

As regards the neural activity associated with verb stimuli, we have reported above that all the verb experimental conditions elicited greater activity relative to nouns in brain regions known to be selectively engaged in verb processing (Willms *et al.*, 2011; Bedny *et al.*, 2008). Among these regions, the left aMTG/STS showed a stronger response to verb phrases including states (e.g., *egli esiste* "he exists") than to phrases including dynamic verbs (e.g., *egli insegue* "he chases"). Therefore, the semantically less prototypical members of verb category (unambiguously established on morphosyntactic grounds) correlate with a greater activity in one verb-selective region, namely, a portion of temporal cortex, anterior to the region showing dynamicity effect for nouns.

What could underlie this result? One possibility is that the marked members of verb category, that is the more distant from prototypical verbs, are more difficult to treat and hence require more processing in the brain. Another possibility, which partially stems from the former, is that the stronger response for state verbs compared with dynamic verbs is related to the atypical semantic role of the subject. Indeed, the subject of a state verb has the semantic role of undergoer (patient or theme), whereas typical subjects are actors (agents, efficients or experiencers: see Van Valin & LaPolla, 1997; Givón, 1984). This, however, stems directly from the cores of verb meaning. Further research will be required to investigate the interaction between semantic and morphosyntactic properties in brain processing of nouns and verbs, to fully understand how the brain generates categorical distinctions.

The results of the experiments discussed here provide new evidence that the noun/verb distinction in the lateral temporal cortex (LTC) is related to the representation of verb and noun as multifactorial categories, defined by features belonging to different dimensions (see above). The formal (i.e., morphosyntactic) dichotomy refers to a cluster of semantic and functional properties determining the complex mapping relationships between grammatical categories and semantic distinctions. These properties are prototypically distributed across members of the two categories of verb

and noun. A morphosyntactically unambiguous noun such as *destruction*, which denotes a dynamic event, may have more verb semantic properties than a morphosyntactically unambiguous verb of condition such as *to exist*, which is non-dynamic, stable in time and persistent in space. The representation of the noun/verb distinction in the brain appears to be grounded in the link between grammatical category specific morphosyntactic representation and a combination of semantic, functional (and, probably, pragmatic) features. Therefore, either a verb morphosyntactic template or a property (or a cluster of properties) belonging to the other dimensions of verb prototype, which do not necessarily co-occur, may drive verb-selective neural activity. In fact, state verbs, presented in morphosyntactically unambiguous contexts (e.g., *ciò esiste*, "this exists"), elicit a strong response in verb-selective brain regions, despite their semantically low prototypicality, and even correlate with increased activity in one region, compared with the semantically more prototypical dynamic verbs. On the other hand, dynamic nouns denoting activities and events, presented in morphosyntactically unambiguous contexts, such as *la distruzione,* "the destruction" and *l'inseguimento,* "the chase", elicit a stronger response than non-dynamic more prototypical nouns in a brain region showing strong verb-selectivity and, despite their clearly nominal morphosyntax, are associated with a more similar pattern of activation to verbs, relative to state and object nouns. The first result relies on a semantically higher markedness/lower prototypicality of states relative to dynamic verbs, given their being equally members of verb category as established on formal grounds and, therefore, their bearing verb morphosyntactic markers. The second result is related to the sharing of semantic features between dynamic nouns and prototypical verbs.

In addition to the main results discussed above, we wish to briefly report two further results relevant to the investigation of principles underlying the organization of linguistic units in the brain.

1) A diverging trend has been observed between frontal regions (left IFG and MFG) and temporal regions (left pMTG and aMTG/STS), as only temporal regions showed an interaction between grammatical category (verb vs. noun) and semantic class (dynamic vs. non-dynamic). Frontal regions respond selectively to verb phrases compared with noun phrases, with no modulation of semantic and functional features. We can, therefore, suppose that the noun/verb distinction in frontal regions is first and foremost (or solely) based on a formal

organizational principle, distinguishing between verbs and nouns as morphosyntactically determined categories. Temporal regions, instead, respond selectively to verbs, as morphosyntactically distinct from nouns, but are also sensitive to the semantic distinctions grounded in verb and noun prototypes, which is in line with results showing that these regions are implicated in conceptual processing (Wei *et al.,* 2012). Further research is needed to investigate the interaction between frontal and temporal regions in representing grammatical categories, to fully understand how the complex mapping relationship between semantics and morphosyntax is captured in the brain. A first indication of how a specific semantic feature of verbs modulates neural activity in temporal regions is provided in §3.

2) Verb selectivity in temporal regions was stronger for nouns without verbal root, such as *escursione* "excursion" or *identità* "identity", than for nouns having a shared root with a verb, such as *distruzione* "destruction" or *possesso* "possession". We might thus suppose that the presence of a verbal root affects neural response to nouns and, therefore, determines verb selectivity independently of the morphosyntactic template. This hypothesis will be tested in a future study, also aimed at exploring how morphological derivation interacts with other dimensions of noun and verb processing.

3. *The representation and organization of event concepts in the brain: The Telic/Atelic distinction*

We have shown above that semantics plays a role in modulating neural response to verbs and nouns in temporal regions. Specifically, an interaction between prototypical semantic features of verbs and morphosyntactic representations of either verbs or nouns underlies verb selectivity in left pMTG and aMTG/STS.

Here a question arises: what is the specific role of single verb semantic features that operate at the interface between semantics and morphosyntax? Here we purpose to address this question. We begin by investigating the role of telicity, to assess whether the telic/atelic distinction is captured in verb selective brain regions found to be sensitive to semantic distinctions. Since we found a stativity effect for verbs in the left aMTG/STS, in the two experiments described above, here we expect this result to be confirmed after

telicity manipulation. Viceversa, we hypothesize a telicity effect in the left pMTG[8].

Exploring the semantic bases for brain processing of verbs leads to exploring the way we represent and organize event concepts in the brain (taking the term "event" here to neutrally refer to any event type, from actions to relations, from change of state processes to states). Telicity, indeed, is the property distinguishing events that necessarily entail a specified endpoint, which prototypically corresponds to a change of state or location (e.g., *assassinare* "to murder", *arrivare* "to arrive")[9], from events with no temporal and spatial delimitation or final state (e.g., *inseguire* "to chase", *stare* "to stay"). The endpoint is an inherent part of the telic event, without which the event could not be what it is. Therefore, *murdering the politician*, for instance, necessarily implies a change of state; if the end state is not attained, then the politician cannot be said to have been murdered (Vendler, 1967; Dowty, 1979). The distinction between telic and atelic events maps onto the distinction between telic and atelic verb predicates[10] (Bertinetto, 1986; Van Valin & LaPolla, 1997; Bonomi & Zucchi, 2001).

Why should this distinction be captured in the brain? Telicity is one of the most pervasive propertis of human languages. It plays a crucial role in language organization, change and acquisition, in both spoken and signed languages, independently of language-specific features (Grose *et al.*, 2007; Alexiadou *et al.*, 2004; Weist, 2002; Slabakova, 2001; Van Valin & LaPolla, 1997; Levin & Rappaport Hovav, 1995; Antinucci & Miller, 1976). A large set of complex mapping relationships between semantics and morphosyntax is governed by telicity, across diverse languages (Tenny, 1994; Romagno, 2003, 2004, 2005b, 2006). Here, we only wish to mention the well-known phenomenon of split intransitivity and the distribution of passive constructions. A robust telicity effect on establishing the distinction between unaccusative and unergative verbs is attested crosslinguistically (Sorace, 2000,

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[8] The finding that the left pMTG showed a dynamicity effect for nouns, in the two experiments described in §2, is consistent with this hypothesis. Telicity, in fact, implies dynamicity.

[9] The representation of a change of state/location, and the consequent affectedness of the direct internal argument necessarily entail telicity (Tenny, 1994). However, telic verbs may not necessarily imply a highly affected argument: e.g., "to find", "to lose", "to obtain". On telicity as graded category, see Romagno (2005a: 13-25).

[10] I use the term "verb predicates" instead of "verbs", in order to include both predicates involving inherently telic verbs, such as *to die* and predicates involving compositional telic verbs, such as *to eat*. On telicity as a property determined at the verb phrase level, and not simply and not always by a verb itself, see Verkuyl (1972), Tenny (1994).

2011, van Hout, 2004, Romagno, 2002; Jezek, 2000; Cennamo, 1999; Van Valin, 1990, Legendre, 1989, among many others). In Dutch, for instance, «telic one-argument verbs are unaccusative, whereas atelic one-argument verbs are unergative» (van Hout, 2004: 60). In addition, the first passive constructions that Italian and English children acquire involve a telic transitive verb (Pinker *et al.*, 1987; Tomasello & Bates, 2001), and there are languages in which passive formation is related to the degree of telicity of verbs: in Russian, for instance, passive applies only to telic transitive verbs, such as "to kill" and "to build", but not to atelic transitive verbs, such as "to call" and "to see" (Fici Giusti, 1994: 43 ff.; Keenan, 1985; Jackendoff, 1972). Moreover, electrophysiological data suggested that the telic/atelic distinction influences on-line sentence processing in the syntactic re-analysis of object reduced relative clauses (Malaia *et al.* 2009).

Evidence of the neural correlate of the telic/atelic distinction has been provided by a recent experiment, in which fMRI methodologies were used in conjunction with verb stimuli to covertly investigate whether the brain distinguishes between telic and atelic events (for a complete description of this study, see Romagno *et al.*, 2012, in press). The study compared patterns of neural response following implicit processing of inherently telic and atelic Italian verb infinitives, matched for frequency (Bertinetto *et al.*, 1995), word length in letters, number of core arguments (Thompson *et al.*, 2007), animacy of the first (or sole) argument, and emotional features, such as valence (positive vs. negative) and arousal (calm vs. excited) (Bradley & Lang, 1994). In order to isolate the role of telicity in modulating neural activity, we also controlled for the potential effect of competing semantic and sensorimotor verb properties, such as dynamicity, agentivity, durativity, concreteness and imageability.

The twenty-two right-handed native Italian volunteers who participated in the study performed a delayed match-to-sample task similar to the task used in the two experiments decribed in §2. In this task, that covertly assessed the representation of telicity, four infinitives (e.g., *camminare* "to walk"*, inseguire* "to chase"*, parlare* "to talk"*, cercare* "to search") were presented sequentially for 1.5 seconds each and separated by a white screen (0.5 s each). Each set of infinitives, which included one condition (telic vs. atelic), was followed by a gap of 7 seconds (while volunteers viewed a fixation cross), and a 1.5 seconds-presentation of a probe stimulus consisting of an inflected verb form (e.g., *camminano* "[they] walk"). Volunteers had to indicate whether or not the probe matched one of the four preceeding infinitives, by pressing a button with their right or left thumb, respectively (for further

details on materials and methods, behavioral results and fMRI results, see Romagno *et al.*, 2012, in press).

It was found that the left pMTG showed a significantly stronger response to telic as compared to atelic verbs, during the encoding phase only (i.e., when volunteers had to read the four infinitives included in each block), thus revealing an implicit processing of the telic/atelic distinction.

These results provide the first evidence that neural activity in the left pMTG is modulated by telicity, and thus indicate that an organizational principle based on the telic/atelic distinction underlies verb processing and event knowledge in the brain. This principle may also explain findings from previous studies that have not directly assessed the representation of telicity. A telicity effect, in fact, may underlie differences in verb production (Lee & Thompson, 2004) or in the patterns of neural response between unaccusative and unergative verbs (Shetreet *et al.*, 2010), since unaccusatives are typically telic, as shown above.

In conclusion, the results of this study show that the human brain distinguishes between telic and atelic verbs and, therefore, appreciates whether events lead to an end or a change of state. Importantly, the telicity effect is independent of any competing sensorimotor and semantic properties, including concreteness, imageability, dinamicity, agentivity, durativity, animacy and number of verb arguments[11].

4. *Conclusions*

To summarize and conclude, the results of the studies described in the present paper show that:

1) brain processing of the noun/verb distinction is related to the representation of verb and noun as graded multifactorial categories, defined by features belonging to different dimensions, as both morphosyntax and semantics affect neural responses to verbs and nouns;

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[11] In addition to the main results discussed above, we found differences in responses to atelic verbs, with increased activation for atelic states (e.g., *to exist*) relative to atelic activities (e.g., *to walk*) in aMTG/STS. This result confirms the aMTG/STS results of the study described in §2 and extend them by disentangling the dynamic/non-dynamic distinction from the telic/atelic distinction. Interestingly, a somewhat related preference for low-motion mental action verbs (e.g., *to think*) relative to high-motion action verbs (e.g., *to kick*) in the same region was observed in previous works (Bedny *et al.*, 2008, 2011).

2) the interaction between features belonging to different dimensions is
    grounded in the prototypical representation of the two categories, since
    either a category specific morphosyntactic template or a property (or
    cluster of properties) belonging to the other dimensions of verb/noun
    prototype may drive selective neural activity. A morphosyntactically
    unambiguous noun, such as *distruzione* "destruction", which has more
    verb semantic properties than a morphosyntactically unambiguous
    verb, such as *esistere* "to exist", is associated with a more similar pattern
    of activation to verbs, relative to semantically more prototypical nouns;

3) there are differences between frontal and temporal regions in establish-
    ing a hierarchic relationship between formal and semantic features,
    since the noun/verb distinction in frontal regions appears to be first and
    foremost based on a formal organizational principle, distinguishing be-
    tween verbs and nouns as morphosyntactically determined categories,
    whereas temporal regions show an interaction between morphosyntax
    and semantics, as they appear to be sensitive to the semantic distinc-
    tion grounded in verb and noun prototypes. Further research is needed
    to fully understand how frontal and temporal regions interact in repre-
    senting the complex mapping relationship between grammatical catego-
    ries and semantic distinctions;

4) different semantic properties appear to have different weights in modu-
    lating selective neural responses to verbs and nouns, as telicity modu-
    lates activity in a brain region selectively engaged in verb processing (left
    pMTG), independently of any other semantic property.

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