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Exploring the neurocognitive basis of language processing: the case of word classes and the key role of interface semantics

ABSTRACT: In the present paper, we address the question of the linking mechanisms of the multifactorial and graded conceptual space with the formally discrete language structures by 1) investigating the neurocognitive basis of interface semantics and 2) exploring the representation of word classes in the brain. Data from cognitive neuropsychological and brain imaging studies are discussed, and an answer is provided to certain critical aspects of the relationship between conceptual categorization and linguistic categorization.

KEYWORDS: Conceptual categorization, linguistic categorization, interface semantics, word classes, cognitive neuropsychology, fMRI.

> «Io sono fatto di parole, magari silenziose; quel poco che so, sono parole,
> stringhe di eventi che ritornano nella loro sequenza non solo grammaticale
> e sintattica ma nella logica razionale o irrazionale del ricordo,
> e mi rifanno il mondo e mi rinarrano»
> (Lamberto Maffei, *Elogio della parola*).

1. The neurocognitive basis of language and the intepretation of the world

A series of experiments on the split brain, originated from a collaboration (which dates back to the late 1950s/early 1960s) between the neurophysiologist and

neurosurgeon Joseph Bogen, the neurobiologist, neuropsychologist and Nobel laureate Roger W. Sperry and his graduate student Michael Gazzaniga (who, then, became the godfather of modern split-brain science) have shown: 1) the specialization of the left hemisphere for language[1]; 2) the specificity of the left-brain mechanism to find relationships between events and entities: the left brain is constantly trying to provide a rational explanation of the world, to interpret it (Gazzaniga 2011, Gazzaniga 2005, Gazzaniga et al. 1996, Gazzaniga & Sperry 1967). The function of «interpreter» of the left-brain system – as Gazzaniga called it (Gazzaniga et al. 1996, Roser & Gazzaniga 2006, Gazzaniga 2011) – is, then, related to the neurocognitive basis of language processing: «in general terms, the left hemisphere appears to be dominant in terms of language and speech functions and to possess the capacity to 'interpret' the actions produced by both hemispheres» (Gazzaniga et al. 1996: 1255; cf. Maffei 2018, Maffei 2014).

The neuroscientific observation that the neural network specialized for language is the same that is responsible for rational thinking, in which resides the neurocognitive basis of how we represent, categorize and interpret the world (Maffei 2018, Maffei 2014, Gazzaniga 2011, Popper & Eccless 1977) parallels a long tradition in linguistic and cognitive sciences showing that languages are cognitive tools that encode the way in which speakers represent, organize and categorize the world (e.g., events, entities, abstract notions, etc.): languages do not convey a fixed image of the reality but, rather, an interpreted reality (de Saussure 1916, Sapir 1921, Berlin & Kay 1969, Rosch 1978, Lakoff 1987, Ramat 1999, Taylor 1995, Lazzeroni 2002, Lazzeroni 2012, Cohen & Lefebvre 2005, Romagno 2016, among many others). Each language interprets the world differently, as linguistic structures testify to the way in which human beings represent and organize the world in historically determined cultures: «l'uomo, la sua unicità […]» sono «espressi da una stringa di parole che la ragione infila nella collana della storia»[2] (Maffei 2018: 18). Language is the most distinctive neurobiologically-

1. On the divided brain and, in particular, on the relationship between asymmetry and the brain, see McGilchrist (2019). It is worth mentioning that lateralization is a complicated issue, which has been largely debated in neuroscience. For instance, certain dominant language functions have been also associated to the right hemisphere: these are related to processing prosody and emotional gesturing. The right hemisphere, in fact, appears to have a significant role in modulating the affective components of speech. However, there is a general agreement, supported by robust and consistent evidence from different perspectives and research methods, on the dominant role of the left hemisphere to provide the neural underpinning of language in right-handed people. For a comprehensive review of these issues, see Friederici (2011).
2. «The human being, his unicity [. . .] are expressed by a string of words that the reason threads onto the necklace of history».

dependent human property, but the actualization of language systems is socio-historically dependent and, therefore, arbitrary:

> Opera naturale è ch'uom favella;
> ma cosí o cosí, natura lascia
> poi fare a voi secondo che v'abbella.[3]
> (Dante, *Paradiso*, XXVI, 130-132)

Observations on the arbitrariness of linguistic systems date back many centuries (see Aristotle *De Interpretatione*, Giles of Rome *De Regimine Principum* III, II, 24, Thomas *Summa Theologica* II, II: cf. Rotta 1909: 186 ff.) and examples of it, involving different dimensions of language, from formal to functional – in Croft's terms (Croft 1991, Croft 2001) – have been largely discussed in modern linguistics from different perspectives (see Sapir 1921, Whorf 1956, Berlin & Kay 1969, Croft 1990, Lazzeroni 2002, Lazzeroni 2012, among many others). To mention only a few well-known cases, the number of basic color terms varies in the languages of the world from two to twelve (Berlin & Kay 1969); categories such as time and number are differently encoded in different languages: «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; see also Sommerfelt 1962); certain languages distinguish between the notion of 'two' (expressed by the dual) and that of 'more than one' (expressed by the plural), while others do not (e.g., Ancient Greek vs. English or Italian: cf. Plank 1989); English uses three words (*time* vs. *wheather* vs. *tense*) to refer to entities denoted by the sole word *tempo* in Italian.

To summarize, languages function as an autonomous system of classification and, therefore, of knowledge, as they encode the way in which speakers represent, interpret and categorize the world.

Consequently, in order to understand the neurocognitive basis of language processing, that is to identify language components that are neurobiologically determined and hence universal, it is necessary to investigate the neurocognitive basis of linking conceptual space (that is, the way in which we represent and categorize the world) with linguistic structures and, specifically, conceptual categories with linguistic categories. A crucial issue, then, arises: conceptual space is multifactorial and graded, whereas language systems are formally discrete; the noetic *continuum* enables an infinite number of possible interpretations that languages encode in discrete forms. In this paper, in order to address the question of how conceptual categorization interacts with linguistic categorization, we start by investigating the mechanisms for encoding a multifactorial and graded reality into formally discrete language structures: the neurocognitive basis of these mechanisms, in fact, is almost entirely unknown.

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3. «That mankind speaks, a work of Nature is,/ but if in this or that way, Nature then/ leaves you to do according to your pleasure». (Langdon, 1921).

Prior studies on conceptual representation, primarily focused on entities and only secondarily on events, provided evidence on the role of perceptual, sensorimotor and more or less abstract properties that do not directly and specifically affect the architecture of grammar: therefore, they contribute to understanding aspects of the neural representation of semantic knowledge (including the organization of conceptual categories independent of language: Binder et al. 2009, Fairhall & Caramazza 2013, Kemmerer 2014, Handjaras et al. 2016, among many others), but do not contribute significantly and specifically to understanding the neural architecture of the interface between concepts and grammar, that is the neurocognitive principles underlying the organization of meaningful linguistic units in complex and coherent morphosyntactic systems.

1.1. The interface between concepts and grammar

Our study aims at investigating the interface between concepts and grammar and, in particular, between semantics and morphosyntax, in order to understand the neurocognitive basis of what we call interface semantics (Romagno 2017)[4], that is, the conceptual-semantic components that link multifactorial (and graded) conceptual-semantic representations with formally discrete morphosyntactic systems. These components include properties such as telicity, agentivity, dynamicity, relationality, individuation (Vendler 1967, Tenny 1994, Levin & Rappaort Hovav 1995, Van Valin & LaPolla 1997, Romagno 2017, among others). To mention only a few well-known issues, telicity distinguishes events like 'to die' and 'to arrive', which necessarily entail a specified endpoint, from events like 'to walk' and 'to talk', with no temporal and spatial delimitation or final state, and is responsible, for instance, for morphosyntactic features such as the distribution of temporal adverbials like 'in X time' (*John arrived in half an hour* vs. **John walked in half an hour*: Bertinetto 1986, Van Valin 1990, Verkuyl 1993; Krifka 1998) and resultative constructions in English (*the river froze solid* vs. **Dora shouted hoarse*: Tenny 1994, Levin & Rappaport Hovav 1995), and co-occurs with the lack of agentivity (i.e., the lack of the actor's control on the event) in the auxiliary selection in compound tenses, in various languages (Van Valin 1990, Sorace 2000, Sorace 2011, van Hout 2004, among others). Individuation characterizes entities that can be delimited in space and time and, then, identified as distinct from others, and is responsible for the distribution of determiners and quantifiers: e.g., 'two bottles' vs. 'some water' (Chierchia 1998a, Chierchia 1998b, Chierchia 2010, Rothstein 2010).

It has been shown that the semantic regularities in the composition of classes of words that have the same morphosyntactic behavior do not rely on the denoting components of word meaning but, rather, on interface semantics, which is shared by words independently of differences and similarities in denotation (Vendler 1967,

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4. On terminological issues and further details on the various approaches to the distinction between interface semantics and other components of word meaning, see Romagno 2017: footnote 2.

Dowty 1979, Levin & Rappaport Hovav 1995, Van Valin & LaPolla 1997, Van Valin 2005): for instance, 'to walk' and 'to talk' differ significantly in terms of denotation; nevertheless, they both represent the prototype of unergative verbs, because they are atelic and agentive, as opposed to unaccusative verbs, that are prototypically telic and unagentive. Split intransitivity (i.e. the distinction between unaccusative and unergative verbs), in fact – as well as many other linguistic phenomena – is morphosyntactically manifested but determined by interface semantic properties (Perlmutter 1978, Levin & Rappaport Hovav 1995, Van Valin 1990, Van Valin & LaPolla 1997, Sorace 2000, Sorace 2011, van Hout 2004, Alexiadou et al. 2004, Romagno 2002, Romagno 2005: 27-42, among many others): e.g., Italian *i ragazzi hanno camminato a lungo* 'the boys have walked for a while' vs. *i ragazzi sono arrivati* 'the boys have arrived'. The former describes an atelic event and represents an unergative pattern, with 'to have' as auxiliary and no agreement of the past participle with the subject (the past participle, in fact, show the unmarked masculin singular form ending in –o); the latter, instead, describes a telic event and represents an unaccusative pattern, in which 'to be' is the auxiliary and the past participle agrees in gender and number with the subject.

Both semantics and morphosyntax do not correspond to homogeneous blocks: certain components of word meaning are morphosyntactically relevant, while others are not, and certain morphosyntactic features are semantically determined (e.g., split intransitivity and passivization: Keenan 1985, Shibatani 1985, Shibatani 1988, Haspelmath 1990, Fici Giusti 1994, Sansò 2003, Romagno 2006) while others are not (e.g., word order in cases like *I went there to do it* vs. **I went there do to it*, the particle/article/possessive movement, etc.: cf. Chomsky 1981). Therefore, to explore the neurocognitive basis of language processing, it is necessary to disentangle different kinds of both conceptual-semantic and morphosyntactic knowledge, in order to see how they differently affect the architecture of language in the brain.

2. The neurocognitive representation of word classes

Word class representation offers a unique opportunity to investigate the neurocognitive principles underlying the interface between conceptual categorization and linguistic categorization and to assess the role of different features in the complex mapping relationship between concepts and grammar. A large number of studies using different perspectives and research methods, in fact, have provided evidence that word classes such as verb and noun display a *continuum* defined by several parameters involving different dimensions, as shown in Table 1 (Ross 1972, Lyons 1966, Givón 1984, Hopper & Thompson 1984; Vogel & Comrie 2000, Sasse 2001, Baker 2003, Ramat 2009, Evans & Osada 2005, Simone 2008, Simone & Masini 2014, Bisang 2010, Croft 2010, Panagiotidis 2015, Romagno 2012a, Romagno 2016; among many others): prototypical members of each class show a cluster of features shared by the other class members in different degree.

	VERB	NOUN
morphosyntactic versatility	+	−
semantic class	dynamic event	"first order" entity
time stability	−	+
existence in space	transitory	persistent
valency	≥1 (relational)	0 (non-relational)
semiotic function	predication	reference
pragmatic function	comment	topic

Table 1. Prototypical properties of verb and noun.

Nonetheless, it has been shown that word class distinction critically operates in the actualization of grammar, where word class-specific information is crucial to produce and comprehend words in their appropriate context (Romagno 2016): for instance, four or five year old children are able to assign grammatical categories to pseudowords (and, consequently, to produce the correct verb vs. noun form), when they appear in the syntactic context appropriate to each category, as exemplified by the following sentence-completion task (Gleason 1958): *yesterday he . . . (ZIB)* (target form = *zibbed*) vs. *there are two . . . (WUG)* (target form = wugs). Word classes encode in discrete forms categories that are multifactorial and graded in terms of conceptual-semantic and functional properties.[5]

Then, to explore the neurocognitive representation of word classes, that is to understand the relationship between grammatical categorization and conceptual representation in word class processing, we need to address the following questions: 1) what is the role of formal vs. semantic properties? 2) are distinct kinds of formal features and of conceptual-semantic knowledge separately stored and accessible?

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5. It is worth mentioning that different languages use different criteria for encoding the word class distinction and the context appropriate to each class may be morphological, syntactic, pragmatic or differently established on the basis of language type. It has been observed that when word class distinction is neutralized at one dimension (e.g., morphology), strategies belonging to different dimensions (e.g., syntax or syntax + pragmatic) may subserve the contrast between predication (typical of verbs) and reference (typical of nouns). On more or less «specialized» languages and on different degrees of flexibility in the typology of word classes, see Hengeveld (1992), Evans & Osada (2005), Ramat (2009), Rijkhoff & van Lier (2013). For a more general discussion of these issues, including the prototypical nature and the "universality" of word classes, see also Romagno (2016): in particular, §4 and §6.

2.1. Grammatical information vs. semantic knowledge in the processing of verbs and nouns: evidence from cognitive neuropsychology

A first possible answer to the above-mentioned questions comes from a study on a patient with Semantic Dementia (Romagno 2012b, Romagno et al. 2010; Papagno et al. 2009), a neurodegenerative disease that belongs to the Fronto-Temporal Dementia Spectrum and specifically entails a deficit in semantic knowledge (Neary et al. 1998, Hodges & Patterson 2007, Gorno Tempini et al. 2011).

Patient MC, an Italian 75-year-old woman, presented with a severe impairment in processing word meaning. Her inferential and referential abilities governing the mapping relationship between concepts and words (Marconi, 1997) were seriously damaged. She was unable to access the meaning of even highly frequent words such as 'cow' and 'to swim', as well as to name events and entities, either in response to a stimulus (e.g., linguistic or visual) or in spontaneous speech. Her semantic deficit equally affected all word classes (Romagno 2012b, Romagno et al. 2010).

We wanted to assess whether the patient retained word class-specific information at the grammatical level, despite her severe impairment in accessing the denoting meaning of words. To this end, we tested her via a sentence completion task including stimuli such as: *la . . . (miagola/fragola) è il mio frutto preferito* 'the . . . ([he] meows/strawberry) is my favourite fruit' vs. *il gatto . . . (miagola/fragola) in giardino* 'the cat . . . (meows/strawberry) in the garden'. The patient was asked to complete the sentences by choosing between the two words 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 provided 100% correct responses. The fact that her semantic knowledge of all the target items used in the grammatical category distinction task was severely impaired suggests that the information governing the processing of verbs and nouns in mutually exclusive morphosyntactic contexts is separately stored and accessible from the denoting meaning of words. The results of this study provide a first hint of a dissociation between word class-specific information (which is morphosyntactic, in this case) and semantic knowledge, and suggest that word class-specific information is not necessarily included in lexical representations. Moreover, they indicate that there is a need for disentangling the role of formal features from that of semantic features in the neurocognitive representation of word classes.

Converging evidence comes from studies using homophones and both words and pseudowords. Well-known experiments conducted by Alfonso Caramazza and his collaborators – among others – have shown that English-speaking patients are able to produce words like *judge* or pseudowords like *wug* in nominal but not verbal context, or viceversa: when asked to complete sentences including noun and verb homophones, like *these people judge, this person . . . – this is a judge, these are . . .*, patient RC, for instance, was able to produce *judges* only in the nominal context, while patient JR only

in the verbal context (Shapiro & Caramazza 2003, Shapiro et al. 2000). These studies show that the processing of word class distinction is independent of the signifier, as patients were able to produce the same word form in either nominal or verbal context, and independent of word meaning: in fact, verb and noun homophones share the core semantic components, and pseudowords have no real meaning.[6]

3. The processing of interface semantics: evidence from Semantic Dementia

We said that semantics – as well as morphology and syntax – is composite and not homogeneous in nature: certain components of word meaning (interface semantic properties such as telicity, dynamicity, individuation, etc.) are specifically relevant to grammatical patterns, while others (the denoting components of word meaning) are not. Therefore, we can suppose that different kinds of semantic knowledge are neurocognitive distinguishable and distinctly affect the representation of word classes and, in general, the architecture of language in the brain.

As expected, the above-mentioned study of the Semantic Dementia patient MC provided evidence of a dissociation between certain interface semantic properties governing the morphosyntactic behavior of verbs and nouns and the denoting meaning of verbs and nouns and suggested that Semantic Dementia patients may be selectively impaired in processing different kinds of either morphosyntactic or semantic knowledge. Patient MC, in fact, was severely impaired at the denoting meaning of words and significantly impaired at processing non-semantically determined morphological and syntacic features. Nonetheless, she performed very well in all the tasks testing her access to Interface Semantics (Romagno 2012b, Romagno et al. 2010).

To provide only a few examples, she was tested on telicity, via a sentence completion task involving the distribution of the temporal adverbials 'in X time' vs. 'for X time': *Mario è morto . . . (IN/PER) tre giorni* 'Mario died . . . (IN/FOR) three days' vs. *Mario ha passeggiato . . . (IN/PER) un'ora* 'Mario walked . . . (IN/FOR) an hour'. 'In X time', which has a delimiting value, occurs only with telic verbs denoting a delimited event, such as 'to die', as opposed to atelic verbs, such as 'to walk', which denotes an event with no specific delimitation or final state. The syntactic frame was identical in both sentences of each pair; in addition, both verbs were compatible with either 'for' or 'in': e.g., 'the man <u>died for</u> his country', 'the man <u>walked in</u> an unusual way'. Therefore, the principle underlying the distribution of the two different patterns cannot be purely syntactic in nature. Rather, the syntactic representations appear to be driven by Interface Semantics. Patient MC was not able to access the denoting meaning

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6. Further evidence is provided by studies of word class-specific deficits restricted to one modality of output (speech vs. writing: Caramazza & Hillis 1991, Hillis et al. 2003, Rapp & Caramazza 2002): that either noun or verb processing is spared in one modality rules out a deficit in the conceptual-semantic representation as the cause of the dissociation.

of the target verbs used in this and other tasks, but her knowledge of the interface semantic properties of those verbs was preserved.

The pattern of performance was the same in the tasks testing her processing of the interface semantics of nouns. For instance, we tested her on the distinction between mass/countable and uncountable nouns that relies on differences in individuation: nouns such as 'dog' and 'table', which are more individuated in space and time and, therefore, able to be counted, can take both definite and indefinite article, plural markers and quantifiers that necessarily denumerate (e.g., 'one', 'two', 'many', 'each'), but cannot take quantifiers that do not necessarily denumerate (e.g., 'little', 'much'). Viceversa, nouns that are less individuated and, counsequently, uncountable, such as 'water', 'milk' and 'sand' show the opposite behavior (Chierchia, 1998a, Chierchia 1998b, Chierchia 2010; Rothstein, 2010): *there is a/*much dog in the garden* vs. *there is *a/much sugar in wine*.

The patterns of performance of brain-damaged patients is highly informative of the representation of both conceptual-semantic and grammatical information. Dissociations of linguistic abilities depending, for instance, on semantic vs. morphosyntactic processing or, more specifically, on distinct kinds of either conceptual-semantic or grammatical features are crucial to demonstrate the neurocognitive independence of these dimensions: for instance, if the processing of the denoting components of word meaning is impaired, while the processing of interface semantics is preserved, like in the case of patient MC, one may conclude that the former is not causally involved in the latter. Moreover, correlating the patients' performance with regional brain damage and, consequently, establishing the so-called "functional locus" of the impairments (Caramazza 1986) allow to explain different mechanisms within a coherent system of language processing. But, unfortunately, brain lesions are often too extensive to provide precise anatomical information and to allow for significant correlations. Therefore, integrating cognitive neuropsychological studies with brain imaging studies is necessary for a more comprehensive understanding of the questions addressed here.

4. Word class distinction and interface semantics: evidence from fMRI

In the functional magnetic resonance imaging (fMRI) studies that we will discuss below, we aimed at disentangling formal features from prototypical semantic features of word classes and investigating the interaction between word class-specific information and interface semantic properties, such as dynamicity, telicity and relationality, in order to test the processing of word class distinction against interface semantics (besides other conceptual-semantic and sensorimotor properties investigated in previous studies).

4.1. Verb/noun distinction and the processing of dynamicity

In two experiments, we tested the noun/verb distinction against dynamicity, an interface semantic property that distinguishes processes like walking or thinking from states like existing or possessing.

Besides the long debated issue of the neuroanatomical correlates of verbs and nouns, brain regions that selectively or preferentially respond to verbs compared with nouns have been identified. The most robust and consistent finding across studies, tasks and languages is an involvement of the left lateral temporal cortex (LTC), including the posterior middle temporal gyrus (pMTG), and of the inferior frontal gyrus (IFG) in verb processing (Hernández et al. 2014, Moseley & Pulvermüller 2014, Kemmerer 2014, Yu et al. 2013, Romagno et al. 2012, Peelen et al. 2012, Willms et al. 2011, Bedny et al. 2008, Tyler et al. 2008, Shapiro et al. 2006, Kable et al. 2005, among others). We wanted to know whether differences in dynamicity between previously-used verbs (e.g., *to run*) and nouns (e.g., *the table*) modulate verb-selective brain regions (Peelen et al. 2012). Then, we compared the patterns of neural activity associated to four experimental conditions: dynamic verbs (e.g., 'to walk', 'to chase'), non-dynamic verbs (e.g., 'to exist', 'to possess'), dynamic nouns (e.g., 'the destruction', 'the attack'), non-dynamic nouns (e.g., 'the identity', 'the possession').[7] We found that word class-specific information is captured in the brain independently of differences in dynamicity between stimuli: in fact, regions previously associated to verb processing, including, in particular, the left pMTG and the left anterior middle temporal gyrus/superior temporal sulcus (aMTG/STS), have shown an overall greater activation for verbs compared with nouns. These regions, that we also identified by an independent localizer contrast between action verbs (e.g., 'to jump') and object nouns (e.g., 'the bottle'), responded selectively to both dynamic and non-dynamic verbs when contrasted with both 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').

Then, word class-specific information appears to have a significant impact on the brain signal, that cannot be reduced to differences in dynamicity between verbs and nouns.

However, further findings are of special interest to the understanding of the role of different properties in the representation of word classes: 1) a preference for states compared to dynamic verbs was found in the left STS, but not in the left pMTG, which may suggest a different distribution of verb representations in the left LTC, related to the distinction between stative and dynamic verbs; 2) activity selective for action verbs, relative to state verbs, was found posterior to verb-selective clusters, indicating that nearby but distinct clusters may represent verbs and actions (Figure 1).

7. For a detailed description of experimental design, materials and methods and fMRI analyses adopted in both the experiments, see Peelen et al. 2012.
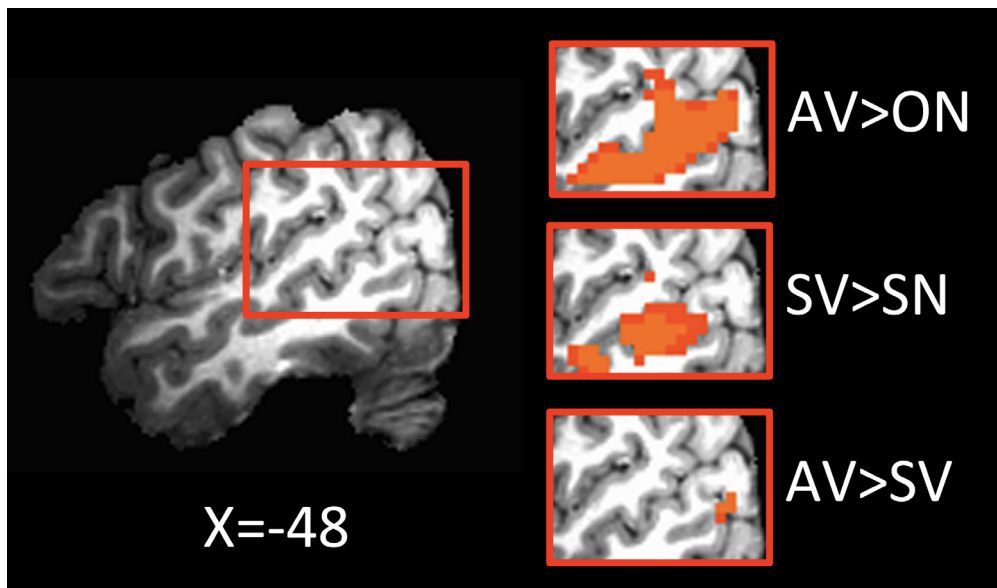
Figure 1 (Peelen et al. 2012). Verb- and Action-selective clusters in the left LTC. Results of three independent contrasts are shown: action verbs vs. object nouns (AV > ON: top row); state verbs vs. state nouns (SV > SN: middle row); action verbs vs. state verbs (AV > SV: bottow row).

4.2. The representation of verbs in the brain: the role of telicity

The experiments discussed in §4.1. have revealed variations related to dynamicity in the organization and representation of verb classes within the left LTC: the left STS responded more to states than dynamic verbs, whereas there was no difference between states and dynamic verbs in the left pMTG; in addition, action verbs (which are typically dynamic) were associated to a cluster located posterior to the portion of the left LTC (including pMTG) that showed selectivity for verbs overall, relative to semantically matched nouns.

Therefore, we wanted to further investigate the role of interface semantics in verb representation. To this purpose, we addressed the neural correlates of telicity: our hypothesis was that telicity modulates verb-specific neural responses in the left LTC (Romagno et al. 2012). Telic verbs, such as 'to die', 'to go home', 'to build a house', that typically denote a change of state, are necessarily dynamic, even if dynamic verbs may be atelic (e.g., 'to walk', 'to talk'). Then, we asked whether the activation of the left LTC and, specifically, of the left pMTG for verbs was driven by telicity, rather than dynamicity. Telicity is a fundamental interface semantic property that plays a crucial role in language organization, change and acquisition, in both spoken and signed languages, independently of language-specific features (Slabakova 2001, van Hout 2004, Hodgson 2009, Grose et al. 2007, Malaia et al. 2009, among others). Also, we may suppose that it carries an important evolutionary function, as the ability to

appreciate whether events continuously unfold over time, with no spatial delimitation or final state or, alternatively, entail an endpoint and/or a change of state (e.g., *to chase an animal* vs. *to catch an animal*) is necessary for selecting appropriate behaviors to successfully meet environmental and social demands.

In the whole brain, we compared the patterns of neural activity associated with telic and atelic verbs, and found that the left pMTG selectively responds to telic verbs as compared to atelic, when all the other competing semantic components (including dynamicity and agentivity) have been controlled for and no behavioral differences have been found between the experimental conditions (Figure 2).[8]
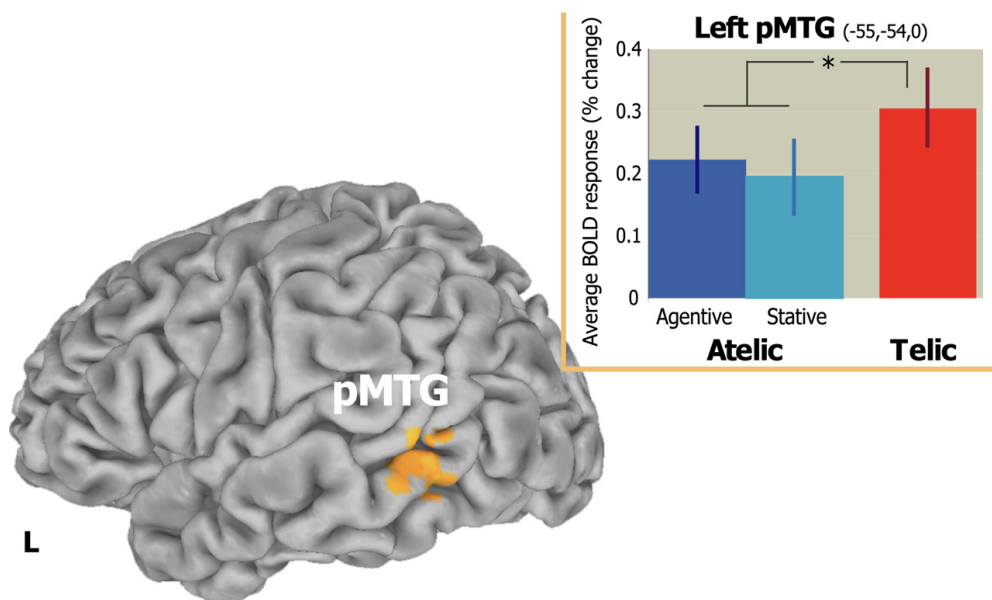

Figure 2 (Romagno et al. 2012). Left pMTG activation for telic compared to atelic verbs: telic vs. atelic state contrast; telic vs. atelic activity contrast.

This study provides evidence that neural activity in the left pMTG is modulated by telicity and, thus, indicates that event knowledge and verb processing in this region are specifically related to the representation of telicity. These findings raise the possibility that the left pMTG represents that kind of conceptual-semantic properties of verbs, that we call Interface Semantics.

8. For a detailed description of experimental design, materials and methods and fMRI analysis, see Romagno et al. 2012.

4.3. The neural correlates of verbs, adjectives and nouns: grammatical categories vs. relational items

In the attempt to go a step further in the study of the relationship between interface semantics and grammatical category-specific information, not only in the neuro-cognitive representation of verbs but also, more extensively, in the processing of word class distinction, we investigated the role of relationality in determining the patterns of neural responses to distinct word classes (Romagno et al. forthcoming). Relationality is characteristic of verbs: verbs, in fact, necessarily entail an inherent relation between the denoted event and its participants and between the participants, or between the denoted event and its sole participant.[9] Other word classes, such as nouns and adjectives, instead, may be either relational ('mother', 'similar') or non-relational ('table', 'bright'). In this study, we included also adjectives, which have long been a «forgotten grammatical category» (Meltzer-Asscher & Thompson 2014) in neuroscientific research. Adjectives represent a «swing-category» (Givón 1979: 13) between verbs and nouns (Dixon 1977, Dixon 2004, Thompson 1988, Wetzer 1996, Stassen 1997, Lombardi Vallauri 2000, Rinaldi et al. 2004): therefore, their processing must involve dimensions and mechanisms implicated in either verb or noun processing. Investigating their neural correlates may, then, contribute to the understanding of how word class distinction is represented in the brain and to assess the role of different features in processing each class.

We compared fMRI activity evoked by Italian verbs, relational and non-relational nouns, relational and non-relational adjectives, controlled for a series of crucial features, including interface semantic properties (e.g., dynamicity vs. stativity). The experimental design, then, included eight conditions: relational vs. non-relational nouns: *distruzione* 'destruction', *affinità* 'compatibility, similarity' vs. *tavolo* 'table', *pietra* 'stone'; relational vs. non-relational adjectives: *simile* 'similar' vs. *sottile* 'thin'; one-argument and two-argument physical activities: *camminare* 'to walk', *inseguire* 'to chase'; one-argument and two-argument mental activities/states: *gioire* 'rejoice', *temere* 'to fear'.[10] All the stimuli have also been rated on familiarity, imageability and concreteness: the role of these features in word class representation, in fact, is still debated (Rodríguez-Ferreiro et al. 2011, Hernandez et al. 2014, Moseley & Pulvermüller 2014, Abel et al. 2015, Hoffman et al. 2015).

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9. It is worth specifying that besides the long debated issue of the impersonal verbs and the verbs with actant H, and the highly questioned case of verbs with no thematic relations (see Lazard 1998, Langacker 2006, and the various contributions in Fiorentino 2003, among others), which are largely beyond the scope of the present paper, relationality is crucial to verbs. In fact, it is manifested in the semiotic function of predication (e.g., verbs predicate something about someone or something, whereas nouns typically refer to a «first-order entity»: Lyons 1977), in the semantic valency (which determines argument structure and is, then, ≥1) and in the syntactic valency (i.e., the syntactic realization of the logical argument structure): cf. Hengeveld & van Lier (2008), Hengeveld & van Lier (2010).
10. For a detailed description of experimental design, materials and methods and fMRI analyses, see Romagno et al. forthcoming.

We found that familiarity, imageability and concreteness significantly correlated with neural response in language-sensitive regions (including the left LTC and, in particular, MTG: Fedorenko et al. 2010), which indicates that taking into account the specific role of these features is necessary to untangle the neurocognitive mechanisms underlying word processing. Then, the fMRI analyses have been conducted after regressing out the scores of familiarity, imageability and concreteness from the neural response: different sets of brain regions showed sensitivity to verbs, adjectives and nouns as distinct grammatical categories, indicating that word class-specific information is captured in the brain independently of relationality.

4.4. The neurocognitive representation of word classes: open questions

There is a need for further investigation into the representation of word classes in the brain. Evidence from a variety of experimental techniques and research methods indicates a complicated scenario of a distributed network including frontal, temporal and parietal regions, responsible for the processing of word classes (Havas et al. 2015, Crepaldi et al. 2013, Crepaldi et al. 2011). Crucial questions remain open: 1) what is the role of single areas in representing word class-specific information? 2) which verb/adjective/noun properties are represented in these areas and how? 3) which properties are dominant in determining the neural activity associated to each class? It has been shown that telicity plays a crucial role in the representation of verbs in the left pMTG (Romagno et al. 2012) and that the higher complexity of the event, the number of core arguments and of possible subcategorizations may be responsible for differences in the processing of different verb classes in both frontal and temporal regions (Romagno et al. 2012, Meltzer-Asscher et al. 2015, Thompson et al. 2009, Shetreet & Friedmann 2012, Shetreet et al. 2010). We believe that the study of the neurocognitive representation of word classes needs to take into account their multifactorial and gradient nature, in order to understand the relationship between the features that are crucial for either conceptual or linguistic categorization. More specifically, one needs to explain: 1) how they interact in word class processing, 2) how the neurocognitive representations of different word class properties are interconnected.

5. Conclusions

In the present paper, we have shown that in order to understand the neurocognitive basis of language processing it is necessary to investigate the linking mechanisms of the multifactorial and graded conceptual space with formally discrete language structures.

We have demonstrated that a key role in these mechanisms is played by interface semantic properties, such as telicity, dynamicity, individuation, etc.

We have also argued that the processing of interface semantics may be neurocognitively independent of the processing of other components of word meaning

(the denoting components) that do not directly and specifically affect morphosyntax.

In addition, we have accounted for the fact that word classes represent a key issue at the interface between conceptual categorization and linguistic categorization and, consequently, offer a unique opportunity to investigate the neurocognitive principles underlying the complex mapping relationship between grammar and different dimensions of meaning.

Finally, we have shown how the understanding of the neurocognitive representation of word classes requires the disentangling of formal features from semantic features, the assessment of the role of interface semantic properties, as well as a fine-grained account of the multifactorial and gradient nature of verbs, adjectives and nouns.

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