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Research Report

Event-related potentials to event-related words: Grammatical class and semantic attributes in the representation of knowledge

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A R T I C L E I N F O

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A B S T R A C T

A number of recent studies have provided contradictory evidence on the question of whether grammatical class plays a role in the neural representation of lexical knowledge. Most of the previous studies comparing the processing of nouns and verbs, however, confounded word meaning and grammatical class by comparing verbs referring to actions with nouns referring to objects. Here, we recorded electrical brain activity from native Italian speakers reading single words all referring to events (e.g., *corsa* [the run]; *correre* [to run]), thus avoiding confounding nouns and verbs with objects and actions. We manipulated grammatical class (noun versus verb) as well as semantic attributes (motor versus sensory events). Activity between 300 and 450 ms was more negative for nouns than verbs, and for sensory than motor words, over posterior scalp sites. These grammatical class and semantic effects were not dissociable in terms of latency, duration, or scalp distribution. In a later time window (450–110 ms) and at frontal regions, grammatical class and semantic effects interacted; motor verbs were more positive than the other three word categories. We suggest that the lack of a temporal and topographical dissociation between grammatical class and semantic effects in the time range of the N400 component is compatible with an account in which both effects reflect the same underlying process related to meaning retrieval, and we link the later effect with working memory operations associated to the experimental task.

1. Introduction

A central issue in the cognitive neuroscience of language is the functional organization of word representations and how such structure is implemented in the brain. Word meaning seems to be a good candidate to serve as an organizing parameter of lexical knowledge, with words sharing semantic attributes clustered in semantically organized neural networks. Supporting this claim, selective brain impairment in the processing of words belonging to specific semantic categories (e.g. fruits, animals, or tools) has been described (for a review, see Shelton and Caramazza, 1999; Humphreys and Forde, 2001), and several neuroimaging studies have shown discrete cortical activation patterns associated with different types of word

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meanings (for a review, see Martin and Chao, 2001 and Bookheimer, 2002). Sensory information associated with words can determine the cortical areas involved in their processing. For example, reading words with strong olfactory associations in their meaning activate olfactory regions of the brain (González et al., 2006), and when generating colour words, a region involved in the perception of colour is activated (Martin et al., 1995). Likewise, electrophysiological studies have shown that word processing related to actions involving different body parts (e.g. arms or legs) activate motor and premotor cortex in a somatotopic fashion. Leg words (e.g. "kick") produce the largest activation around the vertex consistent with leg motor representation, whereas arm words (e.g. "pick") activate the left inferior-frontal area (Hauk et al., 2004; Hauk and Pulvermüller, 2004; Shtyrov et al., 2004; Pulvermüller et al., 2005; Tettamanti et al., 2005). Thus, evidence has begun to accrue that sensory and motor information associated with the reference of a word contributes in some way to its neural representation.

In addition to semantics, some clinical and experimental data suggest that words from different grammatical classes, especially nouns and verbs, could be processed in (at least partially) distinct neural systems (e.g., Caramazza and Hillis, 1991; Shapiro et al., 2006). In particular, it has been argued that whereas noun processing would engage left temporal areas, verb processing would engage left prefrontal areas, including inferior-frontal areas. Importantly, whereas older studies indicated that the lexical representation for nouns and verbs involved different neural systems (e.g., Caramazza and Hillis, 1991; Silveri and di Betta, 1997), more recent work suggests that different neural systems for nouns and verbs are engaged because of differences in the morphological processes that apply to nouns and to verbs (Shapiro et al., 2006; Pulvermüller & Shtyrov; see Vigliocco et al., submitted for publication, for a discussion for these two views).

Neuropsychological studies have reported double dissociations between noun and verb processing, with some patients showing a greater deficit on verbs compared to nouns (Miceli et al., 1984; Caramazza and Hillis, 1991), while others show the opposite pattern (Damasio and Tranel, 1993; Miozzo et al., 1994). However, these studies confounded the grammatical class distinction between nouns and verbs with the semantic distinction between objects and actions as patients were asked to name pictures of objects or actions (for a meta-analysis, see Mätzig et al., 2009). Neuroimaging evidence supporting grammatical class distinctions in the brain is inconclusive. Whereas some studies have failed to find processing differences between nouns and verbs (Siri et al., 2008; Tyler et al., 2001; Li et al., 2004; Vigliocco et al., 2006), others have found specific activation only for verbs but not for nouns (Warburton et al., 1996; Perani et al., 1999; Fujimaki et al., 1999), and one study has reported selective activation for verbs and nouns (Shapiro et al., 2006). However, it is again the case that in those studies that have found specific activations, there was a confound between the semantic and grammatical class distinction. Hence, verb-specific activation can for example be interpreted in terms of engagement of action-related knowledge.

In a PET study, Vigliocco et al. (2006) manipulated grammatical class and controlled for semantic differences using only (Italian) nouns and verbs referring to events (e.g., *corsa* [the run]; *correre* [to run]). In the absence of the confounding correlated semantic distinction between objects and actions, no noun- or verb-specific activations were found. Instead, there was significant activation in left motor cortex for motor word processing and significant activation in left inferior temporal and inferior-frontal regions for sensory word processing. These findings indicate that it is semantic rather than grammatical properties that drives word representations and suggest that word comprehension involves the activation of modality-specific representations that are linked to word meaning. However, it is possible that such a lack of effect might be due to the poor temporal resolution of PET. In the present study, we use electrical brain activity recorded from the scalps of healthy adults to disentangle the contribution of semantics and grammatical class to visual word recognition.

Event-related brain potentials (ERPs) have been used extensively in the study of word processing (Barber and Kutas, 2007). The excellent temporal resolution of this technique has allowed the identification of very early correlates of the processing of lexico-semantic and lexico-syntactic information during word recognition. For example, the N400 component has been related to semantic processing, and it has been suggested that it is a good index of the ease of accessing information within long-term semantic memory and the integration of this with the local context (Kutas and Federmeier, 2000). The distribution of the N400 component could also be sensitive to the activation of different semantic networks. It has been reported that the N400 associated with animal names differs from the N400 related to tool names: it is larger at frontal sites for animals in comparison with tools, with the opposite pattern at parietal sites (Kiefer, 2001, 2005; Sitnikova et al., 2006). Therefore, the modulation of this component can be a useful tool to study how words are stored and retrieved.

Unfortunately, the picture arising from the available ERP data related to grammatical class effects is at least as confusing as that of the neuroimaging research reviewed above. Several studies have analyzed the processing of verbs and nouns during sentence or text reading, and therefore they have been more focused on the syntactic roles of these words (Osterhout et al., 1997; Brown et al., 1999; Federmeier et al., 2000). In a more restricted context of pairs and triads of words, Khader et al. (2003) (see also Rösler et al., 2001) showed that the N400 effect associated with semantic priming was not affected by the grammatical class of the words. However, differences in the scalp distribution of ERPs evoked by nouns and verbs led the authors to conclude that access to these two types of items involves cell assemblies that are topographically distinct. Further evidence compatible with such a view comes from a study in English with minimal phrases (e.g. "the + noun" or "to + verb"), which reported larger N400 amplitudes to nouns as compared to verbs (Lee and Federmeier, 2006).

The studies summarized above used words in phrasal and sentential context. One could argue that in order to better assess effects of grammatical class, experiments should use single words to reduce morphological and syntactic integration processes. However, studies using this procedure have also given rise to conflicting results

(Preissl et al., 1995; Dehaene, 1995; Koenig and Lehman, 1996; Pulvermüller et al., 1999a,b; Kellenbach et al., 2002). Pulvermüller et al. (1999b) compared three different lists of German words: action verbs, nouns with strong action associations, and nouns with strong visual associations. Current source density (CSD) analyses of the ERPs showed topographic differences depending on grammatical class between 120 and 220 ms after the average recognition point of the auditorily presented words. Differences between visual nouns and action verbs were similar to those between both types of nouns, and no differences emerged between action nouns and action verbs. The authors concluded from these results that differences in brain activity associated with grammatical class depend on word meaning rather than lexico-syntactic properties. Effects on the P200 component could reflect early semantic activation of words. On the other hand, in a similar experiment with visual word presentation in Dutch, Kellenbach et al. (2002) compared nouns and verbs that were classified depending on their semantic features: abstract words, words with visual and motor features (e.g. manipulable objects), and words with only visual features (e.g. nonmanipulable objects). ERP comparisons showed differences depending on both grammatical class and semantic dimensions in the time windows of the P200 (250–350 ms) and N400 (350–450) components. However, as no statistical interaction between these effects was observed, the authors claimed that grammatical class and semantic effects are independent, and that therefore both dimensions are relevant in the neuronal organization of knowledge.

Thus, ERP effects associated with grammatical class have shown both semantic and grammatical class effects but have led to opposite conclusions about whether these effects reflect basic differences in the composition and distribution of semantic features. It should be noted that even when semantic dimensions were manipulated in some of these experiments (e.g. comparing abstract, visual, and motor words), in none of them was the impact of these variables on the grammatical class distinction controlled or minimized. In those experiments, nouns still referred to objects and verbs still referred to actions. Thus, it is difficult to disentangle effects due to grammatical class from effects due to conceptual/semantic differences between objects and actions.

Moreover, as discussed in Vigliocco et al. (submitted for publication), nouns and verbs also differ with respect to the morphological processes they involve: nouns are marked for number (singular or plural) and in richly inflect languages also for other features such as gender (masculine, feminine, or neuter) and case. Verbs are marked for number as nouns, but then they can also mark temporal aspects (present, past, and future) and the agent of the event (first, second, or third person). These differences render plausible the possibility that distinct neural systems are engaged in the morphological processing of nouns and verbs, as suggested by Shapiro et al. (2006). In a recent MEG study, Pulvermüller and Shtyrov (2009) analyzed the Mismatch Negativity (MMN) response (Näätänen, 1995) to the same Finnish inflectional suffixes on verbs or nouns. The noun affixes produced stronger brain activation in right superior-temporal cortex, whereas activation for verb affixes was greater in left inferior-frontal cortex. These results are consistent with previous imaging studies that have reported verb-related left inferior-frontal gyrus (LIFG) activation under tasks that involve morphological processing (Tyler et al., 2004; Shapiro et al., 2005). However, a recent study (Siri et al., 2008) found no specific activation of the LIFG for verbs as compared to nouns. In contrast, this area was sensitive to the level of morphological processing for both nouns and verbs. Therefore, LIFG activations could reflect the engagement of morphological processes rather than verb-specific processing. In the present study we used unambiguous Italian words presented without morphosyntactic context or a morphologically related task to reduce the impact of morphological processing.

We used ERPs to study how grammatical and semantic factors affect word processing and whether any grammatical class effect can be observed once the conceptual difference between objects and actions is minimized. Following Vigliocco et al. (2006), we attempted to minimize conceptual differences between objects and actions by using verbs and nouns referring only to events (e.g., *corsa* [the run]; *correre* [to run]). To examine modality-related semantic effects across the grammatical classes of verbs and nouns, we used words referring to motion events (e.g., (la) piroetta [(the) *pirouette*]; (loro) scalano [(*they*) *hike*]) and words referring to sensation events (e.g., (l') odore [(*the*) *smell*]; (loro) annusano [(*they*) *sniff*]). We therefore manipulated grammatical class (nouns versus verbs) and the proportion of semantic attributes associated with words (motor versus sensory) in an experimental design entailing a two by two structure with four experimental conditions: motor nouns, motor verbs, sensory nouns, and sensory verbs. Having reduced the noun/object versus verb/event confound, we can better assess the functional role of the ERP components associated with noun and verb processing during single word reading. Moreover, we compared the noun–verb differences with those between sensory and motor conceptual properties of words, especially in relation to the distribution of the N400 component. In this manner, we can clarify whether grammatical class and a related, but purely conceptual dimension, result in qualitatively different ERP signatures.

2. Results

Grand average ERP waveforms for nouns and verbs (collapsed across semantic attributes) are shown for nine electrode sites in Fig. 1, and waveforms for sensory and motor words (collapsed across grammatical class) are shown in Fig. 2. Visual inspection suggests differences between nouns and verbs starting at around 300 ms. At posterior locations, verbs elicited more positive amplitudes than nouns. Then, at around 450 ms, a longer-lasting difference is observed over frontal sites with the reverse polarity: here, verbs are more negative than nouns. The same pattern can be seen for the sensory–motor comparison. Over posterior sites, the waveforms elicited by motor words are more positive than those for

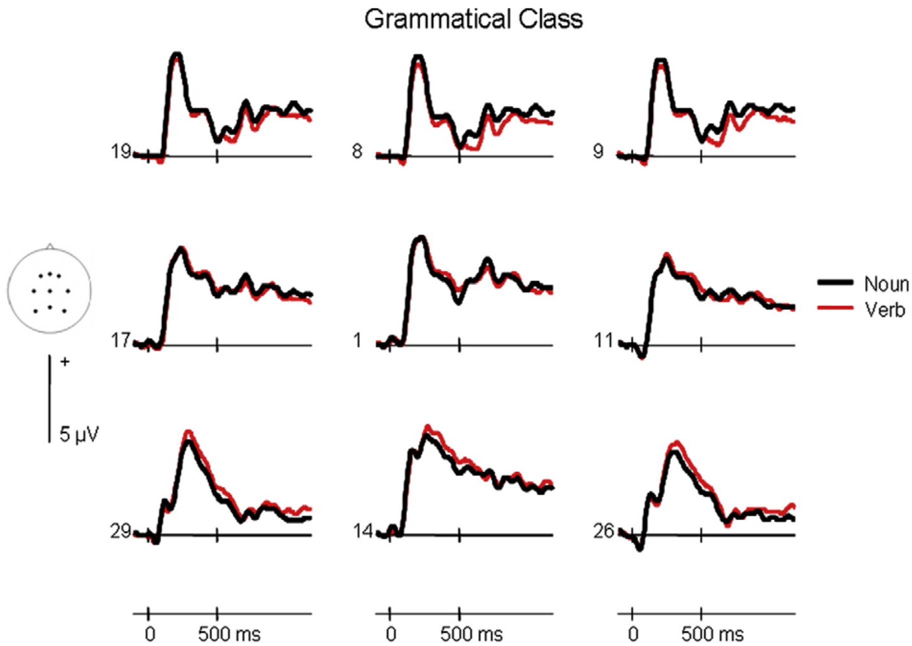

Fig. 1 – Grand average ERP waveforms corresponding to nouns and verbs at nine representative electrode sites (see locations in Fig. 5). Waveforms are collapsed across sensory and motor words. Vertical lines mark the onset of the presentation of the words (t = 0). In this and following figures, positive is plotted upward.

sensory words between 300 and 450 ms. Again, this difference is followed by the reverse pattern at frontal electrodes. This later effect starts around 450 ms and lasts until the end of the epoch. Fig. 3 depicts the topographic distributions over the scalp of the effects associated with grammatical class and semantic information in the two time windows of interest (300–450 and 450–1000 ms). Both effects show similar scalp distributions over central-parietal and right frontal areas. Separate ERP waveforms for the four experimental conditions are shown in Fig. 4 for a representative midline parietal electrode site (Pz). The largest difference is visible between sensory nouns and motor verbs; sensory verbs and motor nouns are associated with values that fall between those two extremes. In addition to these main differences, smaller

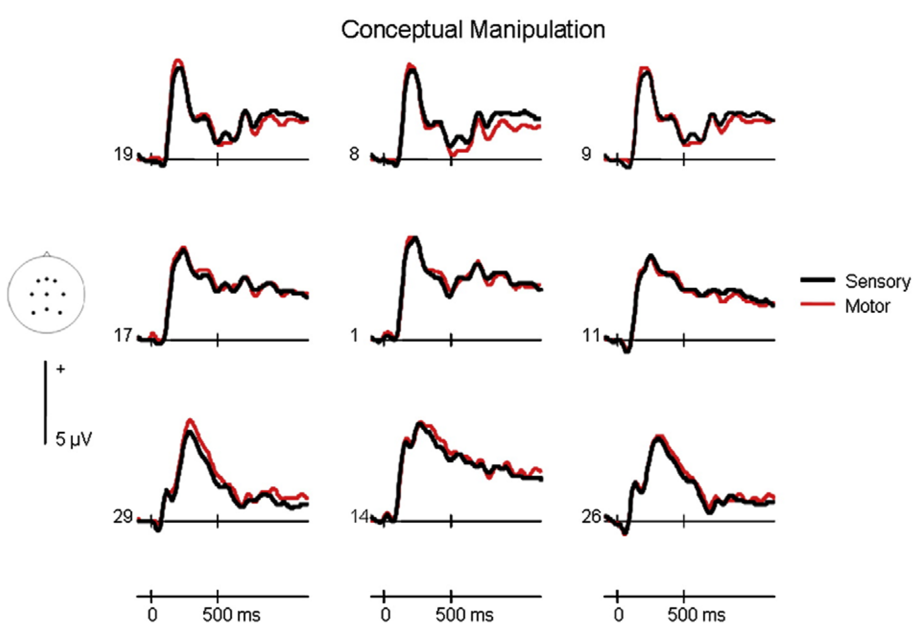

Fig. 2 – Grand average ERP waveforms corresponding with sensory and motor words. Waveforms are collapsed across verbs and nouns.

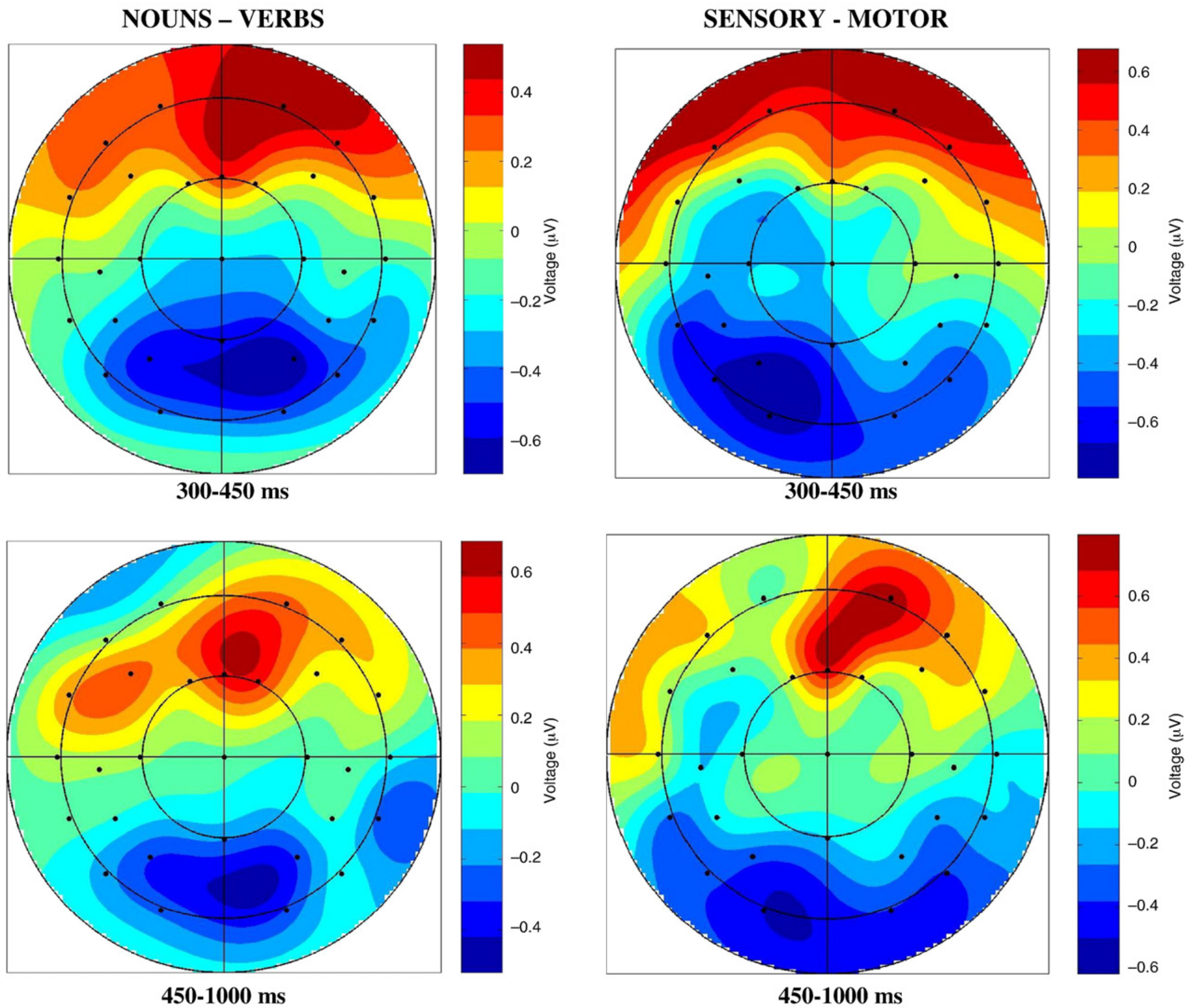

Fig. 3 – Topographical distribution of the grammatical class (left column) and semantic attribute (right column) effects in the two analysed temporal windows: 300–450 and 450–1000 ms. Voltage maps were obtained for the averaged values of difference waves and scaled to the maximum and minimum in each condition.

modulations of the P200 component can be seen at some frontal sites when noun and verbs, and sensory and motor words, are compared (see Figs. 1 and 2). As previous studies have reported early grammatical class effects in the time range of the P200 component, these potential differences were also tested. Statistical analyses are described below for three time windows. The P200 time window was selected on the basis of visual inspection of the grand averages, whereas the other two time windows were obtained after preliminary analyses of consecutive 50 ms windows. The latency windows are consistent with previous quantifications of the P200, N400, and late slow waves.

2.1. *The 175- to 225-ms time window*

An ANOVA including all 29 electrode sites and the two vocabulary factors (grammatical class and semantic attributes) did not determine any main effect of grammatical class [$F(1, 21)=0.9$; $p=0.33$; MSE$=5.07$] or semantic attributes [$F(1, 21)=0.19$; $p=0.19$; MSE$=13.72$] nor interactions of any of these factors with the topographic factor. Potential differences in this time window were restricted to a few frontal electrodes, so a second ANOVA was performed including only three frontal electrodes (8, 9, and 19). This analysis did also not result in a statistically significant main effect or interaction.

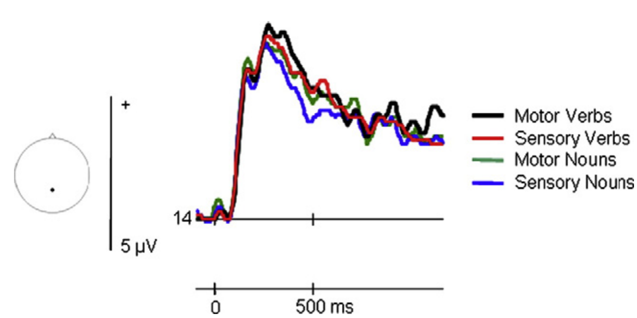

Fig. 4 – Grand average ERP waveforms elicited by motor verbs, sensory verbs, motor nouns, and sensory nouns at the Pz electrode.

2.2. The 300- to 450-ms time window

The ANOVA of mean amplitudes in this time window including all 29 electrode sites and the two vocabulary factors (grammatical class and semantic attributes) resulted in significant interactions between grammatical class and electrode [$F(4.3,\ 89.4)=2.65$; $p<0.05$; $\varepsilon=0.15$; MSE = 0.85] and between semantic attributes and electrode [$F(3.2,\ 68.1)=3.18$; $p<0.05$; $\varepsilon=0.11$; MSE = 0.96]. Mean values for verbs were more positive than those for nouns, and values for motor words were more positive than those for sensory words. Importantly, however, no interactions involving grammatical class and semantic attributes were found. ANOVAs including factors of rostrality (anterior–posterior) and laterality (left–right) showed interactions between Grammatical Class and Rostrality [$F(1,\ 21)=6.74$; $p<0.05$; MSE = 6.4] and between Semantic Attributes and Rostrality [$F(1,\ 21)=6.44$; $p<0.05$; MSE = 9.05]. As in the previous analysis, no other interactions involving Grammatical Class or Semantic Attributes were found.

2.3. The 450- to 1000-ms time window

The ANOVA including all 29 electrode sites and the two vocabulary factors (grammatical class and semantic attributes) resulted in a three-way interaction between grammatical class, semantic attributes, and electrode that just missed conventional levels of statistical significance [$F(4.5,\ 95.2)=2.2$; $p=0.06$; $\varepsilon=0.16$; MSE = 0.87]. However, the ANOVA including rostrality and laterality factors showed a significant three-way interaction between grammatical class, semantic attributes, and the rostrality factor [$F(1,\ 21)=4.63$; $p<0.05$; MSE = 6.38]. Amplitude values were especially larger for verbs with a high degree of motor features in comparison with sensory verbs and motor and sensory nouns, and these differences were larger at frontal sites as compared to posterior sites.

3. Discussion

In this study, we examined brain activity associated with word reading to assess the hypothesis that grammatical class is an organising principle of knowledge in the brain. Single words were presented to participants while both grammatical class (noun–verb) and semantic features (sensory–motor) were manipulated. In contrast to most previous studies, the words we used all referred to events (e.g., “to run” and “the walk”), thus eliminating a confound between grammatical class and semantic domain (object nouns versus action verbs). Moreover, using single word presentation of Italian words, we limited confounding effects of sentence-level processing while at the same time we were able to minimally manipulate morphological processing (i.e., inflections differed for nouns and for verbs). Results showed ERP differences at two time windows following word onset and at two locations across the scalp. We found that both grammatical class and semantic attributes affected ERPs in, crucially, similar ways between 300 and 450 ms after word onset. In this time window, ERPs associated with nouns and sensory words were more negative, at posterior electrode sites, than those associated with verbs and motor words respectively. As we will discuss below, we propose that these results are consistent with a single process underlying both the grammatical class and the semantic manipulations affecting the initial processing of words. Initial differences were followed by a second effect with a maximum at frontal sites, which started when the first effect ended and continued until the end of the analyzed epoch. This frontal effect showed a similar pattern across experimental conditions as the earlier posterior effect, but with reversed polarity (i.e. verbs and motor words more negative than nouns and sensory words). However in this case, the larger difference between motor verbs and the other three word categories resulted in an interaction between the grammatical class and the semantic effects. Finally, our data do not replicate previous reports of noun–verb differences in an earlier time window (e.g. Preissl et al., 1995; Pulvermüller et al., 1999a). Although some trends (in the opposite direction) can be seen in the grand averages affecting the P200 component at frontal electrode sites, these were not statistically significant.

In light of their onset and centro-parietal scalp distribution, the effects observed between 300 and 450 ms point to a modulation of the N400 component. Consistent with our data, previous studies have also reported larger N400 responses to nouns than verbs when they were presented in sentences (Federmeier et al., 2000), minimal phrases (Lee and Federmeier, 2006), or word lists (Kellenbach et al., 2002). The N400 has traditionally been linked to semantic and conceptual processing rather than grammatical or syntactic processing. More specifically, the N400 has been related to meaning activation and long-term semantic memory retrieval (Kutas and Federmeier, 2000). Comparisons between nouns referring to animals and nouns referring to tools have also resulted in the modulation of this component (Kiefer, 2001, 2005; Sitnikova et al., 2006). Therefore, different concepts could require the activation of different types or amounts of semantic features, which may result in amplitude or topographic differences in this time window. Following this interpretation, the differences between nouns and verbs and between sensory words and motor words in our experiment could be understood as a correlate of how meaning-related information is retrieved.

We selected words all referring to events, thus using words coming from the same semantic domain. Moreover, we used norms to guide our selection of items in the motor versus sensory category, thus going beyond intuition in our classification. Nonetheless, it can still be the case that nouns and verbs still differ in their semantic attributes. Recent work from an embodied perspective suggests a remarkably high degree of specificity in activation of the motor cortex to words referring to motion. For example, Glenberg et al. (2008) showed that use-induced plasticity effects do not transfer between right and left hand. Even more remarkably, Casasanto (2009) showed that left and right-handers show differences in behavioural effects and patterns of activation in left and right premotor areas when processing words referring to motion. Nouns and verbs referring even to the same event still maintain some semantic differences; in particular, we would like to argue that whereas verbs may automatically be interpreted in relation to an agent (i.e., movement of a specific person as agent), this may not the case for the nouns. Namely, when subjects process “corre” (s/he runs), they could automatically build a specific and concrete simulation in a manner that would not be possible for the corresponding noun “corsa” (the run), which instead would trigger a more generic simulation of, for example, a race.

Regardless of how one wants to interpret specific differences in the modulation of the N400, the results of the present study show that grammatical class and the semantic distinction between sensory and motor words both modulate the N400 component. N400 effects for grammatical class and the semantic attribute manipulation did not differ in terms of latency, duration, or scalp distribution. As mentioned already, the N400 has previously been related to long-term semantic memory retrieval, and the second effect could be related with the working memory demands of the task. Nonetheless, we found a main effect of grammatical class, even in an experimental design where nouns and verbs were matched for several lexical and semantic variables and, critically, only event-related words were used to minimize the object noun/action verb confound. One could argue that this effect provides support for the view that grammatical class is an organizational criterion of lexical knowledge in the brain, along the lines of the interpretation provided by Kellenbach et al. (2002). Although we cannot reject this possibility (e.g. similar ERP effects on the scalp can originate from different neural sources), the lack of qualitative differences between grammatical class and semantic effects on the N400 can be better explained as resulting from a single process underlying both effects. This idea is supported by converging behavioural, patients, imaging, and TMS evidence (Vigliocco et al., submitted). These lines of evidence indicate that grammatical class, although playing a role in sentence processing, cannot be considered to be an organizational criterion for lexical knowledge in the brain whereas semantic clearly is. Future research will be necessary to test these ideas further.

With respect to the later and more frontal effect, its scalp distribution and long duration resemble previously described effects associated with working memory-related operations (Ruchkin et al., 1995). A similar effect has to our knowledge not been reported in previous studies manipulating grammatical class, so it could be related to the specific task that subjects had to perform in our experiment. The task was to keep a word in memory until the next trial in case a decision had to be made about whether the word was repeated. The late frontal effect may reflect differences in the way in which representations of different types of words can be kept in mind. For example, the effect may reflect the activation of different primary cortical areas (e.g. motor versus sensory) by the working memory system for different types of words.

In conclusion, in a study in which we minimized the conceptual distinction between object nouns and event verbs (by only using words referring to events), we still observed a grammatical class effect in the N400 time window and later on. Critically, in contrast to previous studies, we did not observe any early effect of grammatical class, or any qualitative differences between the signatures of grammatical class and semantics, suggesting that the difference between nouns and verbs and between motor and sensory words has a common semantic origin.

4. Experimental procedures

4.1. *Participants*

Twenty-two volunteers (12 women) participated in the experiment and received monetary compensation. Ages ranged from 19 to 36 years (mean = 26 years). They were all native Italian speakers, with no exposure to a second language before 8 years of age. Before the experiment, they filled in a questionnaire about biographical data in order to exclude subjects with a history of neurological or psychiatric impairment, or with visual problems, as well as to determine hand preference and language history. All participants were right-handed, as assessed by an abridged Italian version of the Edinburgh Handedness Inventory (Oldfield, 1971): LQ > 50. Seven of them reported having one or more left-handed relatives.

4.2. *Stimuli*

One hundred twenty-eight Italian words referring to events were used in a two by two within-subjects design, in which the factor grammatical class (nouns versus verbs) was crossed with the factor semantic attributes (motor versus sensory). Sixty-four nouns and 64 verbs were classified according to the four experimental conditions depending on their associated motor and sensory attributes: motor nouns, motor verbs, sensory nouns, and sensory verbs.

Stimuli were selected from an initial pool of nouns and verbs from Vigliocco et al. (2004). A group of speakers provided lists of properties that they considered salient in defining and describing a large set of words. These properties were then classified as motor, sensory (visual, acoustic, tactile etc), functional (i.e., referring to the function served by the event), and others (i.e., mostly encyclopedic information about the events). Words with a greater proportion of motor than any other feature were selected for the two Motor conditions, while words with a greater proportion of sensory than any other features were selected for the two Sensory conditions (see Table 1 for examples). Because only a small number of Sensory words meeting the inclusion criteria were available for each sensory modality, we included words referring to

Table 1 – Examples of nouns and verbs used as stimuli in the motor and sensory experimental conditions.

	Nouns	Verbs
Sensory	Solletico *[tickle]*	Annusa *[(s/he/it) sniffs]*
	Lampi *[lightning-plural]*	Luccicano *[(they) shine]*
	Ronzii *[buzzes]*	Degustano *[(they) taste]*
Motor	Giravolta *[twirl]*	Scuote *[(s/he/it) shakes]*
	Tuffi *[dives]*	Galoppano *[(they) gallop]*
	Sobbalzi *[jerk]*	Rincorre *[(s/he/it) chases]*

Table 2 – Averaged mean values and standard deviations of the matched lexical variables for each word list.

	Familiarity	Age of acquisition	Imageability	Frequency	Length
Motor Nouns	5.43 (0.83)	4.61 (1.25)	5.23 (0.47)	19.15 (43.31)	8.59 (2.44)
Motor Verbs	5.56 (0.73)	5.05 (1.45)	5.34 (0.56)	24.31 (47.86)	7.21 (1.53)
Sensory Nouns	5.43 (0.95)	4.96 (1.47)	5.33 (0.52)	28.62 (82.74)	7.75 (2.35)
Sensory Verbs	5.70 (0.70)	4.49 (1.18)	5.38 (0.43)	11.25 (25.53)	7.68 (1.71)

several sensory modalities (vision, audition, smell, touch, and taste) in the two sensory conditions. Half of the nouns were presented as singular and half as plural forms; half of the verbs were presented in the third person singular and half in the third person plural, of the simple present tense. Verb–noun homonymy (e.g., the fact that the English word "walk" can be used both as a noun – the walk – or a verb – to walk) is less of an issue in Italian than in English, given the morphological richness of Italian. On average, all conditions were matched in familiarity, age of acquisition, and imageability, as established in a norming study using a group of 30 additional native Italian speakers. Words were also matched in length and lexical frequency according to the CoLFIS database[1] (Laudanna et al., 1995). Values of all the described lexical variables were introduced in one-way ANOVAs and no statistically significant differences between word lists for any of these variables were identified. Descriptive statistics are reported in Table 2.

4.3. *Procedure*

Participants were seated comfortably in a sound-attenuated chamber. All stimuli were presented on a monitor at eye level, around 70 cm in front of the participant. The words were displayed in black lower-case letters against a grey background. Participants were asked to relax and to fixate on the centre of the screen and avoid eye movements other than blinks. Words were displayed one at a time, one after another. From time to time (20% of the trials), a probe word was displayed in upper case. Participants were asked to respond to these probe words, indicating whether or not they were a repetition of the previous word. For half of the probe words the response was "yes" and for the other half the response was "no". Probe words were matched in both length and lexical frequency with the experimental words. Half of the probe words were nouns and half were verbs (in the same morphological form as the experimental words). No experimental stimulus was used as a probe. The sequence of events for each trial was as follows: first a fixation point (+) was displayed for 2000 ms (after the first 1800 ms, the colour of the fixation point turned from dark grey to black to prepare the participant for the upcoming word), then after a 300-ms blank, words were displayed for 300 ms. The inter-trial interval varied randomly between 600 and 1300 ms.

[1] Frequency values were obtained from the same morphological form used in the experiment. The value 1 per million (over the corpus of 3.798.275 words) was assigned to 17 words (3 motor nouns, 4 sensory nouns, 5 motor verbs, and 5 sensory verbs) for which this information was not available.

4.4. *EEG recording and ERP analyses*

Scalp voltages were collected from 31 Ag/AgCl electrodes. Twenty-nine of these were embedded in an elasticated cap (http://www.easycap.de) and the other two were placed over left and right mastoids. Fig. 5 shows the schematic distribution of the recording sites. A midfrontal electrode (Fz of the international 10–20 system) was used as online reference, and the data were re-referenced off-line to linked mastoids (reinstating the online reference site). The vertical and horizontal electroencephalogram (EOG) were recorded bipolarly from electrode pairs situated above and below the right eye and on the outer canthi. EEG and EOG were amplified with a bandwidth of 0.01–35 Hz and digitized (12 bit) at a sampling rate of 200 Hz. Inter-electrode impedances were kept below 5 KΩ for the EEG and below 10 KΩ for the EOG.

EEG epochs starting at 100 ms before word onset and ending at 1180 ms thereafter were extracted from the continuous record. Baseline correction was performed using the average EEG activity in the 100 ms preceding word onset. Epochs were then averaged, excluding trials containing artefacts other than blinks. For each participant, the threshold for rejecting trials was

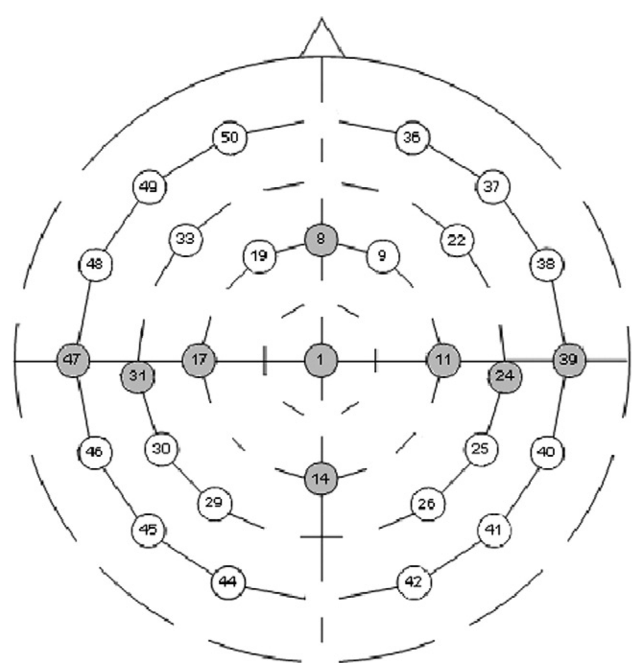

Fig. 5 – Schematic two-dimensional representation of the electrode positions from which EEG activity was recorded (front of head is at the top). Marked sites at midline and central line are those excluded from the supplementary site analyses (see Experimental procedures for further details).

calculated individually and artefacts were confirmed by visual inspection. Additionally, trials were also rejected if A/D saturation occurred or if baseline drift across the recording epoch exceeded ±40 μV. This resulted in the exclusion of approximately 5% of the trials, which were evenly distributed across experimental conditions. A correction procedure based on a standard regression technique was applied to minimize the contribution of blink artefacts to the ERP waveforms (see Rugg et al., 1997). Separate ERPs were formed for each experimental condition, each subject and each electrode site. Mean amplitudes were obtained for different time windows as described in the Results section. For each measure, a repeated measures ANOVA was performed, including factors of electrode (29 sites), grammatical class (nouns versus verbs), and semantic attributes (sensory versus motor). To delineate scalp topographies further, additional ANOVAs were performed excluding 9 electrodes from the midline and the central line (see grey sites in Fig. 5) and adding rostrality (anterior–posterior) and laterality (left–right) factors. All ANOVAs used the Greenhouse–Geisser correction for nonsphericity. Effects involving the electrode, laterality, and rostrality factors will only be reported when they interacted with the experimental manipulations. For presentation purposes, a digital 15.5-Hz low-pass filter was applied to the grand averages.

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