

# Neural Differentiation of Lexico-Syntactic Categories or Semantic Features? Event-Related Potential Evidence for Both

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## Abstract

■ Event-related potentials (ERPs) were used to investigate whether processing differences between nouns and verbs can be accounted for by the differential salience of visual-perceptual and motor attributes in their semantic specifications. Three subclasses of nouns and verbs were selected, which differed in their semantic attribute composition (abstract, high visual, high visual and motor). Single visual

word presentation with a recognition memory task was used. While multiple robust and parallel ERP effects were observed for both grammatical class and attribute type, there were no interactions between these. This pattern of effects provides support for lexical-semantic knowledge being organized in a manner that takes account both of category-based (grammatical class) and attribute-based distinctions. ■

## INTRODUCTION

Dissociations between selective processing impairments have been demonstrated for a range of lexical-semantic categories. For example, brain-injured patients have been reported who are selectively impaired in the processing of nouns but not verbs, or verbs but not nouns. Similarly, dissociations between selective processing impairments have been described for both abstract and concrete concepts, and animate and inanimate entities. Such neuropsychological data have been argued to provide support for the hypothesis that different cortical areas are involved in the processing of different lexical-semantic categories per se, and therefore that such categorical information forms an organizational basis for lexical knowledge in the cortex (e.g., Caramazza & Shelton, 1998; Laiacina, Barbarotto, & Capitani, 1993; Sartori & Job, 1988). Alternatively, it has been suggested that lexical-semantic categories differ in terms of the relative salience of underlying semantic attributes, which define various aspects of semantic knowledge (e.g., what an object looks like, how it is used), in which case category-specific impairments could reflect selective damage to cortical regions supporting the representation of specific semantic attributes (e.g., Gainotti, Silveri, Daniele, & Giustolisi, 1995; Saffran & Schwartz, 1994; Farah & McClelland, 1991; Warrington & Shallice, 1984). The current article aims to contribute to differentiating

between these two accounts by focusing on whether categories and/or attributes form the basis of semantic knowledge organization, with specific reference to the lexical-semantic categories of nouns and verbs, and employing event-related potentials (ERPs) as a measure of neural activity.

## Attribute-Specific Accounts of Category-Specific Deficits

A central tenet of the attribute specificity account of lexical-semantic category processing impairments is that the weightings of the multiple semantic attributes vary between concepts, depending on their salience as determined through acquisition and experience. Because exemplars belonging to any given semantic category are defined by a number of shared semantic features that are central to their representation, selective damage to the cortical representation of a semantic attribute, which is highly salient to the semantic specification of a particular semantic category, will selectively impair knowledge of that category. While a distinction is generally made between sensory/perceptual attributes, which define the concrete (e.g., visual, auditory, tactile) aspects of an object, and functional/nonperceptual attributes, which define the knowledge about function, context, and associations with other concepts, there is increasing evidence that this is an oversimplistic fractionation, as will be discussed below.

This semantic attribute specificity approach has been cited to account for category-specific impairments

observed for both animate and inanimate (manmade artefact) concept categories by arguing that visual-perceptual semantic attributes are critical to the representation and differentiation of animate concepts, while functional attributes essentially define and distinguish inanimate objects (Devlin, Gonnerman, Anderson, & Seidenberg, 1998; Gainotti et al., 1995; Saffran & Schwartz, 1994; Farah & McClelland, 1991; Warrington & McCarthy, 1987; Warrington & Shallice, 1984). Selective animate or inanimate category processing impairments emerge, therefore, through damage to the underlying cortical representations of visual or functional attributes, respectively. Similarly, selective category impairments of concrete word (e.g., pen) processing relative to abstract word (e.g., idea) processing (Carbonnel, Charnallet, David, & Pellat, 1997; Breedin, Saffran, & Coslett, 1994; Sirigu, Duhamel, & Poncet, 1991; Warrington & Shallice, 1984; Warrington, 1975, 1981; for the opposite dissociation, see Coltheart, 1980) can be explained by the centrality of visual-perceptual attributes in the semantic specification of concrete entities (i.e., they refer to objects with a physical reality), which differentiates them from abstract concepts (Carbonnel et al., 1997; Breedin et al., 1994). By the same token, selective impairments of both the lexical-semantic categories of nouns and verbs (Berndt, Haendiges, & Wozniak, 1997; Robinson, Grossman, White-Devine, & D'Esposito, 1996; Hillis & Caramazza, 1995; Daniele, Giustolisi, Silveri, Colosimo, & Gainotti, 1994; Caramazza & Hillis, 1991; Zingeser & Berndt, 1990; Baxter & Warrington, 1985; McCarthy & Warrington, 1985; Miceli, Silveri, Villa, & Caramazza, 1984; Miceli, Silveri, Nocentini, & Caramazza, 1988) have been claimed to reflect the relative salience of visual features in noun (object) representation and functional/motor features in verb (action) representation (e.g., Gainotti et al., 1995; Preissl, Pulvermüller, Lutzenberger, & Birbaumer, 1995).

### Blood Flow Neuroimaging and Lesion Data

The neuroanatomical distribution of perceptual and functional feature representations has been proposed to be aligned with those cortical areas through which the knowledge is acquired and experienced (Gainotti et al., 1995; Small, Hart, Nguyen, & Gordon, 1995; Farah & McClelland, 1991; Warrington & McCarthy, 1987; Allport, 1985). For example, visual-perceptual semantic features (e.g., color, shape) would be represented near the ventral posterior cortical areas, which support high-level visual processing, while functional attributes may be subserved by the dorsal frontoparietal cortical regions, which have been argued to be critical in the processing of somatosensory and motor information (see also Goodale, Milner, Jakobson, & Carey, 1991; Mishkin, Ungerleider, & Macko, 1983). Both lesion and functional neuroimaging studies have provided data largely convergent with this broad

neural distinction, indicating categories critically defined by visual-perceptual attributes (animate/concrete/noun concepts) are subserved by (bilateral) temporal lobe and medial occipital areas (Cappa, Perani, Schnur, Tettamanti, & Fazio, 1998; Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Martin, Wiggs, Ungerleider, & Haxby, 1996; Mummery, Patterson, Hodges, & Wise, 1996; Mummery, Patterson, Hodges, & Price, 1998; Perani et al., 1995; for a review of the lesion data, see Gainotti et al., 1995), while the processing of categories for which functional attributes are most salient (inanimate/verb concepts) involve neural systems in the left fronto-parieto-temporal cortical regions (Perani et al., 1999; Cappa et al., 1998; Damasio et al., 1996; Martin et al., 1996; Mummery et al., 1996, 1998; Warburton et al., 1996; for a review of the lesion data, see Gainotti et al., 1995). Of course, this is a generalized view of the data, and there are also many inconsistencies across a wide variety of often complex paradigms, making any conclusions premature. Nonetheless, while these data provide indirect support for the attribute specificity framework, two neuroimaging studies have specifically investigated whether the neural substrates of semantic knowledge are attribute or category based by directly comparing activations for perceptual and functional semantic attribute knowledge for both animate and inanimate category domains (Cappa et al., 1998; Mummery et al., 1998). Cappa et al. (1998) reported a number of differential activations based on both attribute knowledge and categorical knowledge, with no interactions between the two, whereas Mummery et al. (1998) found that while multiple differential activations were elicited by attribute type, only a single restricted activation was observed for inanimate objects relative to animate concepts. Although the variation in results between these studies requires clarification, the Mummery et al. (1998) data suggest that the cortical organization of semantic representation is primarily on the basis of attribute type, rather than category (at least for the animate/inanimate distinction).

### ERP Studies

ERPs have also been used successfully to probe the structure of semantic memory. Kounios and Holcomb (1994) investigated electrocortical differences between concrete and abstract words in an ERP study using both lexical decision and concrete-abstract classification tasks. An enhanced anterior and right hemisphere maximal negativity was associated with concrete words over the latency range 300–800 msec. This ERP concreteness effect was interpreted as reflecting the activation of visual-perceptual semantic attributes critical only to the representation of concrete words, while the differential scalp distributions of the abstract and concrete word ERPs is consistent with processing of these two word types being subserved by at least partially

distinct neural populations. One ERP study has also provided direct evidence for visual and nonperceptual aspects of semantic representation being subserved by at least partially distinct neural systems. Coltheart et al. (1998) recorded ERPs during a task requiring the selective access and verification of either nonperceptual or visual-perceptual attributes of the referents of concrete nouns. An enhanced anteriorly maximal negativity, somewhat resembling the concreteness effect reported by Kounios and Holcomb (1994), was associated with the processing of visual-perceptual semantic attributes over the latency ranges 300–400 and 600–800 msec. The distinct scalp distributions of the ERPs elicited by the processing of nonperceptual and visual semantic attributes indicated that these index nonidentical neural populations.<sup>1</sup>

Preissl et al. (1995) (see also Pulvermüller, 1996; Pulvermüller, Lutzenberger, & Preissl, 1999a) employed a lexical decision ERP paradigm to investigate processing differences between concrete noun and action verb stimuli, for which preliminary ratings indicated stronger visual and motor associations respectively. Verbs elicited an increased fronto-centrally maximal positivity relative to nouns over the 200–230-msec poststimulus latency range. Although analyses were not performed which enable conclusions to be drawn regarding the distinctiveness of the underlying neuronal sources (see McCarthy & Wood, 1985), Preissl et al. (1995) interpreted the fronto-central effect as indexing the higher motor attribute salience of the action verbs and speculated that the frontal (pre)motor cortices may be involved. Recently, Pulvermüller, Lutzenberger, et al. (1999) have demonstrated similar differences in evoked current source densities (ERPs derived from current source density (CSD) estimates) elicited by nouns and verbs over the 200–230-msec epoch at anterior sites, and also over occipital cortical areas. Verbs elicited more incoming current than nouns over central sites, while nouns exhibited relatively greater incoming current over occipital sites. This pattern of results was interpreted as being consistent with verbs recruiting additional neural generators in or near the (pre)motor cortices, while nouns elicit increased activity in occipital cortical areas involved in visual processing. Pulvermüller, Mohr, and Schleicher (1999) have subsequently shown a similar pattern of effects when nouns with high visual associations were compared to either action verbs or nouns with strong action associations, which did not differ from one another. These data suggest the topographical differences observed may reflect semantic factors rather than lexical class per se. Koenig and Lehmann (1996) also showed that nouns and verbs are subserved by nonidentical neural populations. ERPs were recorded while subjects silently read nouns and verbs, and, using spatial microstate analysis, differential spatial distributions were identified for the neural activity elicited by noun and verb

processing over the somewhat earlier poststimulus latency range 116–172 msec.

### Further Fractionation of Semantic Categories and Attributes

Despite evidence for the perceptual/functional attribute distinction as an organizing principle of semantic representations, the studies discussed so far have not taken into account the probable complexity of semantic attribute descriptions. The claim that broad semantic categories share a single salient attribute type is almost certainly an oversimplification, and attribute-specific fractionations have already been applied to the division of nouns into concrete and abstract words and to the subsequent subdivision of concrete concepts into animate and inanimate objects. A finer fractionation still has been implicated by neuropsychological dissociations between the processing of small manipulable “indoor” objects and large nonmanipulable objects within the inanimate semantic category (Warrington & McCarthy, 1987; Yamadori & Albert, 1973). Warrington and McCarthy (1987) suggested that this dissociation reflects the differential salience of sensory/motor (action) attributes for manipulable and nonmanipulable objects, which implies that not only can semantic categories such as inanimate nouns be further fractionated, but that the broad definition of functional attributes may also be subdivided into more specific attribute types, such as a motor/action component and a more abstract functional knowledge component.

Similar refined attribute-specific fractionations are also possible within the broader category of verbs. The most prevalent type of verb in the literature are action verbs, which are defined by their reference to physical actions, or the salience of motor attributes in their semantic specification (e.g., write). Two additional verb types have been distinguished, however, on the basis of the salience of perceptual and functional attributes (Bushell & Martin, 1997; Grossman, Mickanin, Onishi, & Hughs, 1996; see also Miller, 1972). Motion verbs describe the manner by which an object transfers from one place to another (e.g., flow) and have been argued to have high visual-perceptual content because knowledge about these verbs is acquired and experienced visually. In contrast, cognition verbs refer to mental processes with no corresponding external physical reality (e.g., forget) and can therefore be defined as “abstract” in a similar sense to abstract nouns. A dissociation between motion and cognition verbs has been demonstrated by two studies of patients with Alzheimer’s disease, who were impaired in motion relative to cognition (and perception) verb processing (Bushell & Martin, 1997; Grossman et al., 1996).

### The Current Experiment

While there is evidence that both (inanimate) noun and verb categories may be fractionated into subclasses

**Table 1.** Mean Percentage Correct (Hits) and False Alarms for the Recognition Test, for Each Stimulus Category

	<i>Nouns</i>			<i>Verbs</i>		
	<i>Abstract</i>	<i>Visual</i>	<i>Motor</i>	<i>Abstract</i>	<i>Visual</i>	<i>Motor</i>
% Correct	58 (31.7)	51 (31.0)	53 (28.5)	56 (31.7)	51 (35.9)	59 (32.8)
% False alarms	36 (42.2)	34 (42.8)	41 (31.7)	48 (32.2)	39 (34.6)	35 (35.9)
Discrimination index	0.22	0.17	0.13	0.01	0.17	0.23

The discrimination index is the false alarm rate subtracted from the hit rate, where 0 is chance performance. Standard deviations in parentheses.

differentiated on the relative salience of visual-perceptual and motor attributes in their semantic specification, most studies of noun and verb processing have not controlled for such variations, weakening claims regarding the importance of perceptual or action attributes for the representation of these broad lexical classes. In order to draw conclusions about the reliance of lexical-semantic category distinctions on differential semantic attribute salience, and/or the validity of noun/verb categories per se, these lexical-semantic categories must be compared while systematically controlling for the contributions of different attribute types to the underlying semantic representations. The current ERP experiment was designed to investigate whether processing differences between noun and verb categories can be accounted for by the differential salience of visual-perceptual and sensorimotor attributes in their semantic specifications. Three subclasses of nouns and verbs were selected based on their semantic attribute composition.<sup>2</sup> Abstract nouns (e.g., peace) and cognition verbs (e.g., consider) constituted “abstract” stimuli for each grammatical class, for which both visual-perceptual and motor attributes are not prominent. Nouns referring to nonmanipulable objects (e.g., lamp-post) and motion verbs (e.g., flow) were selected as subclasses of each grammatical category for which visual-perceptual attributes are highly salient, while motor features are not central to their semantic specification. Finally, nouns referring to manipulable objects (e.g., pliers) and action verbs (e.g., sit) served as stimuli for which both visual-perceptual and motor semantic attributes are highly salient. It should be noted that this is not a fully balanced design because of the impossibility of using stimuli for which motor attributes are prominent while visual-perceptual attributes are not.

The recording of ERPs during the processing of these noun and verb subclasses enables processing differences and relative activation time course information to be examined across grammatical class and semantic attribute dimensions, while distributional differences between the ERPs can provide evidence for the distinctiveness of the underlying neural systems. Although the central question addressed by the present experiment is whether noun/verb processing differences are category based (grammatical class: noun, verb) and/or attribute

based (“abstract,” visual, motor), the current design also enables investigation of differential processing effects between semantic attributes across grammatical class. Semantic attribute differences have generally been investigated within a single grammatical class (e.g., concrete versus abstract nouns), so it remains unclear whether comparable differentiations will be found for both grammatical classes.

## RESULTS

### Recognition Data

There were no significant effects in the analysis of the target recognition data (Table 1). There was a significant Class  $\times$  Type interaction [ $F(2,58) = 3.76$ ,  $GG = .033$ ] for the false alarm data, which reflects the somewhat higher false alarm rate for abstract (cognition) verbs, although paired  $t$  tests did not reveal significant differences between this condition and any of the others.

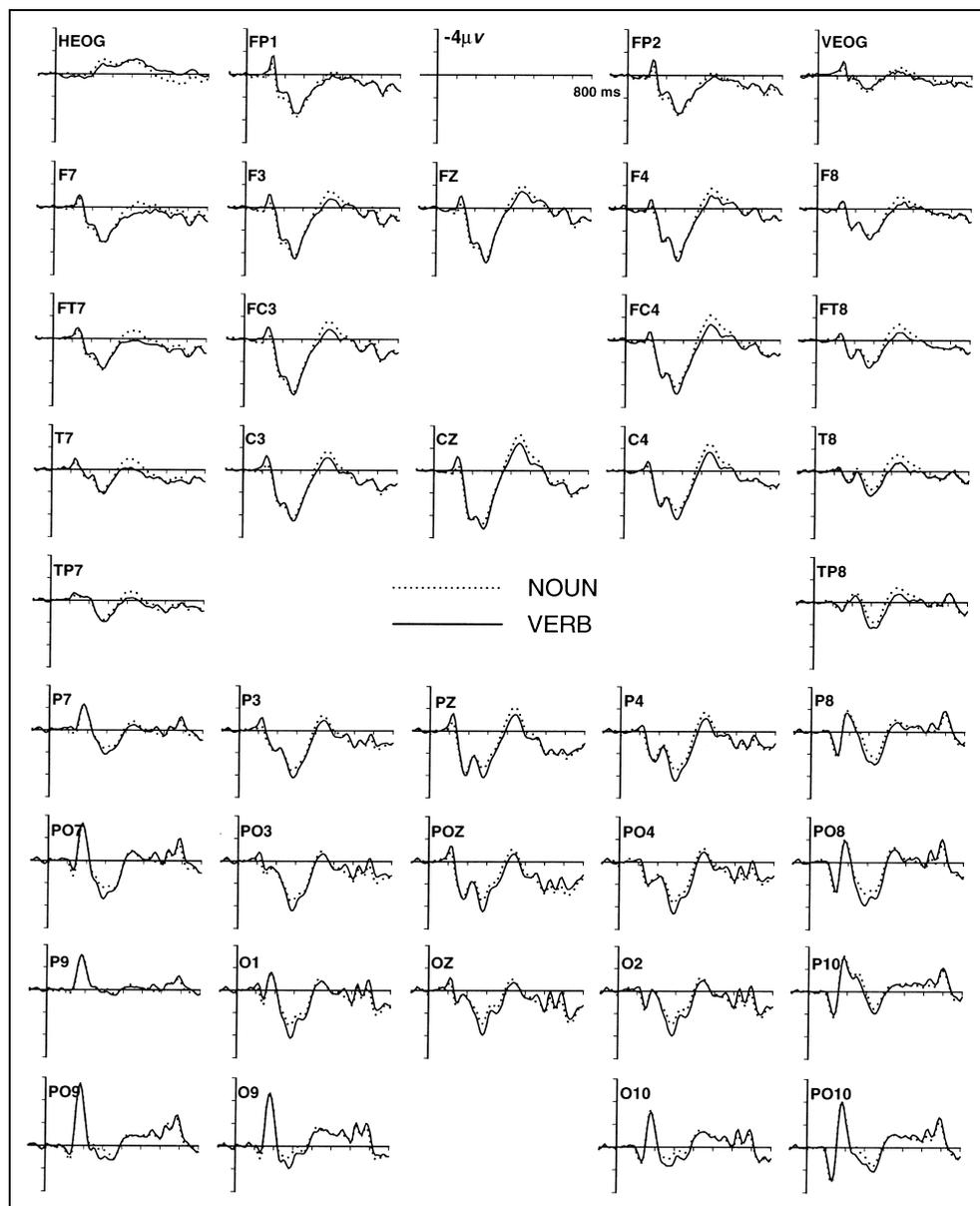
While the accuracy rate for targets in the recognition test was around chance level, the percentage of false alarms suggests that performance was above chance. To test this observation, an index of discrimination performance was calculated (hit rate–false alarm rate), where a value greater than 0 indicates above chance performance (Table 1). An ANOVA revealed that discrimination performance tended to be above chance [ $F(1,29) = 3.18$ ,  $p = .085$ ], while the index did not differ across Class [ $F(1,29) = .52$ ,  $p = .475$ ] or Type [ $F(1,29) = .26$ ,  $p = .771$ ]. The failure of overall discrimination performance to reach statistical significance is likely to reflect the difficulty of the recognition task—the distracter items were designed to be extremely similar to (and therefore confusable with) the critical items, while the large number of stimuli presented in a single block would have further exacerbated the difficulty of the task.

### ERP Data

#### *Absence of Interactions Between Grammatical Class and Semantic Attribute Type*

No significant interactions involving semantic feature type and grammatical class were obtained in the 50 msec

**Figure 1.** Grand average ERPs evoked at 37 scalp sites by nouns and verbs, collapsed over attribute type. The plots are arranged to resemble their positions on the scalp. Negative is plotted upwards.



analyses performed over the latency range 0–800 msec. This indicates that the effects of grammatical class (verbs vs. nouns) did not differ significantly between the semantic attribute types (abstract, visual, and motor) and, conversely, that the effects of semantic attribute type were equivalent for each grammatical class. Therefore, Figures 1 and 3 show the ERPs for nouns and verbs collapsed across semantic feature type (Figure 1), and for abstract, visual, and motor semantic feature types collapsed across grammatical class (Figure 3).

#### Components and Scalp Distribution

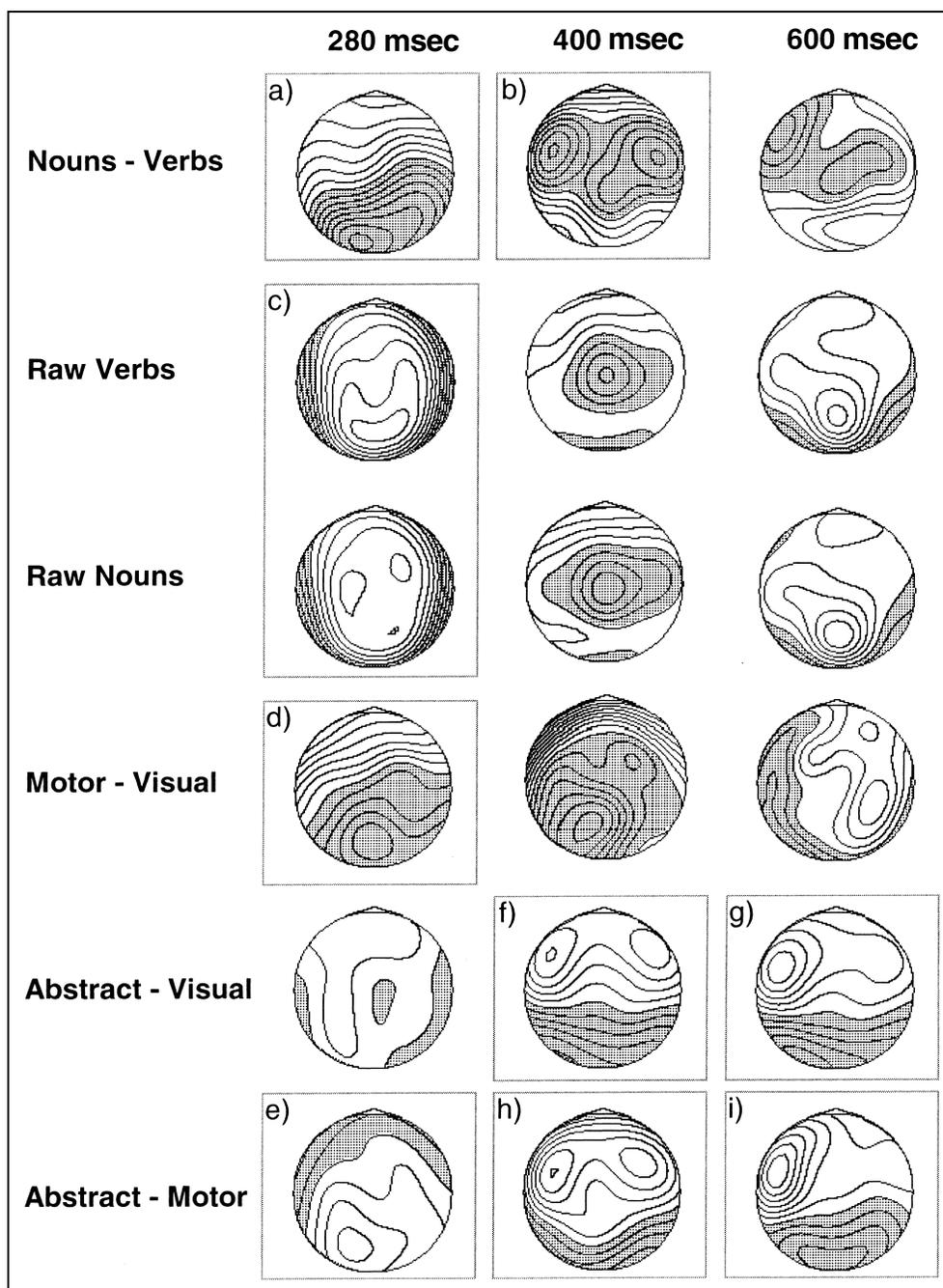
The waveforms in Figures 1 and 3 are characterized by a series of components, including a broadly distributed early negativity (N1) peaking at around 110 msec at all

but the most posterior sites, and a more posterior P1/N1 complex (peaking at ~120 and 180 msec, respectively). Subsequent to these early components is a large broadly distributed positive-going component (P2), with a peak latency between 280 and 350 msec (most posteriorly), which shows a double peak at most sites. These components are followed at all but the most anterior sites by a negative component peaking at around 430 msec (N400) and then a centro-parietally maximal positivity (P3/SW complex).

#### Effects Involving Grammatical Class: Table 2, Figures 1 and 2

250–350 msec (P2). The earliest effect of grammatical class was a posteriorly maximal enhancement of the P2

**Figure 2.** Topographies of differences between grand mean ERPs to nouns and verbs (contour line spacing = 0.1  $\mu\text{V}$ ), raw ERP distribution for nouns and verbs (contour line spacing = 0.4  $\mu\text{V}$ ), differences between grand mean ERPs to motor and visual (contour line spacing = 0.1  $\mu\text{V}$ ), abstract and visual (contour line spacing = 0.2  $\mu\text{V}$ ), and abstract and motor (contour line spacing = 0.2  $\mu\text{V}$ ) semantic attribute types at 280, 400, and 600 msec. The letter labels indicate the maps referred to in the text. The maps represent the head as seen from above, where anterior is upwards, and right is on the right. Shading indicates relatively more negativity.



component elicited by verbs relative to nouns (Figures 1 and 2a: Class main effect and Class  $\times$  Site interaction, 250–350 msec). The rescaled data analyses indicated different neural populations contributed to the ERPs elicited by nouns and verbs in this time interval (see Table 2). Note that while this modulation of the P2 by grammatical class showed a very localized posterior focus, the P2 component itself showed a much wider topographical distribution, extending over the central and frontal regions (Figure 2c).

350–450 (N400). Verbs again elicited greater positivity than nouns over the midlatency range 350–450 msec,

which appears to be a modulation of the centro-parietally maximal N400 component. This effect was centrally maximal and statistically robust over lateral sites only (Figures 1 and 2b: Class main effect and Class  $\times$  Site interaction, 350–450 msec).

*Effects Involving Semantic Attribute Type: Table 3, Figures 2 and 3*

From 250 to 750 msec poststimulus, a complex pattern of ERP effects associated with semantic feature type results from two overlapping effects with distinct topographies:

**Table 2.** Summary of Statistically Significant Effects Involving Class Resulting from 50 msec Analyses

Epoch (msec)	Effect	Midline Sites		Lateral Sites	
		F	p/GG	F	p/GG
<i>P2</i>					
250–350	Class			5.34	.028
	Class × Site	5.45 (3.40)	.013 (.039)	3.19 (2.87)	.024 (.051)
<i>N400</i>					
350–450	Class			6.38	.017
	Class × Site			3.18	.039

Degrees of freedom for Class main effects are (1, 29), whereas for Class × Site interactions, the degrees of freedom are (4, 116) for the midline analyses and (15, 435) for the lateral site analyses.  $p$  =  $p$  value, GG = Greenhouse–Geisser adjusted significance value. Values in parentheses correspond to effects that were significant after rescaling.

a posteriorly maximal effect associated with a relative negativity of the motor word ERP and an overlapping relative positivity associated with the abstract word trace anteriorly.

#### *Motor attribute effect 250–450 msec (P2 and N400).*

Over the 250–350 msec latency range, motor words elicited greater negativity than both the visual and abstract words, which closely resembled each other (Figures 2d and e and 3: Type main effect only, 250–350 msec). This effect initially had a temporal parietal distribution over lateral sites, which expanded to a more widespread posterior maximum on the negative-going flank of the N400 component (Type × Site interactions, 300–350 and 350–450 msec). Comparisons of feature types indicated that the motor word trace differed only from the abstract word ERP over the 250–300 msec interval, while from 300 to 350 msec, the motor words elicited significantly greater negativity than both the abstract and visual words.

#### *Concreteness effect 300–750 msec (P2 and N400).*

Abstract words were associated with increased positivity relative to the visual and motor words anteriorly, onsetting at around 300 msec at lateral sites (Type × Site interaction, 300–350 msec) and persisting over the centro-anterior scalp until 550 msec (Figures 2f and h and 3: Type main effects and Type × Site interactions, 350–450 and 450–550 msec), after which point the effect became left lateralized (Figures 2g and i and 3: Type × Site × Hemi interaction, 550–750 msec). Analyses on the normalized data indicated that the latter part of this effect of attribute type (450–750 msec) can be attributed to differential neural sources (see Table 3).

### **Distributional Comparison of Lexical Category and Attribute Type Effects on the P2 Component**

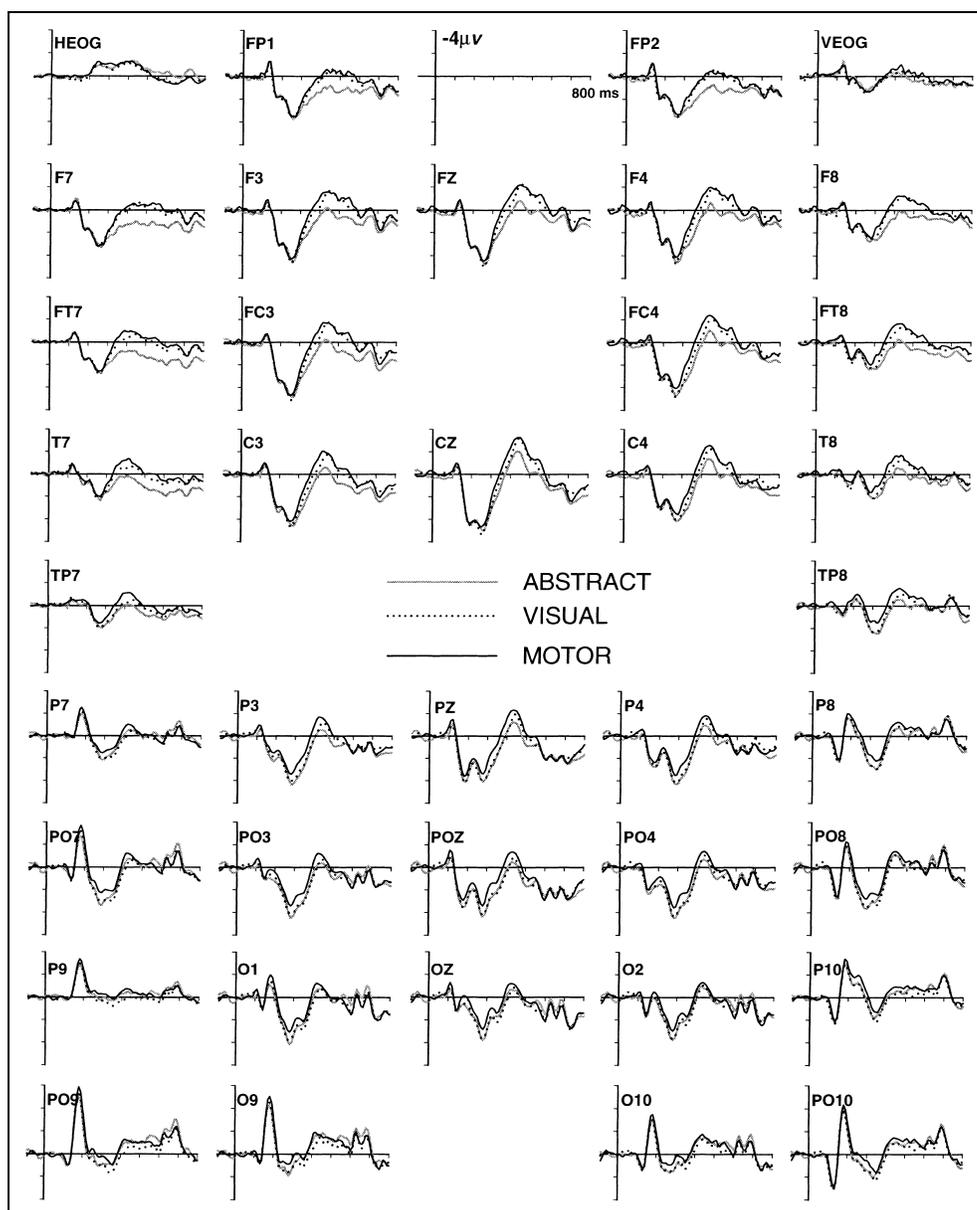
The widely distributed P2 component (250–350 msec) was modulated by both grammatical class and feature

type over the posterior scalp, with verbs eliciting an enhanced P2 relative to nouns, and words with salient motor attributes associated with an attenuated P2 relative to visual and abstract stimuli. The similarity of these effects in terms of latency and distribution prompted a direct comparison of these two effects (Figures 2a, d, and e). The difference between the motor and visual ERPs was averaged for nouns and verbs, and this was compared to the difference between the noun and verb ERPs averaged across motor and visual feature types. This comparison of the Class (noun–verb) and feature Type (motor–visual) effects was performed for midline and lateral sites separately over the latency range 250–350 msec. Of primary interest was whether the two effects differed in terms of scalp distribution, as such a result would indicate independent neural sources for the two effects. No significant interaction between the difference between the two effects and electrode site was found, however, providing no evidence for distinct neural generators.

### **DISCUSSION**

The current experiment investigated whether electrocortical differences observed between nouns and verbs are attributable to a categorical distinction per se, or to differential contributions from underlying semantic attributes. A relatively implicit task was used in an attempt to avoid overt direction of attention to the manipulations of lexical class and semantic attributes, and thereby elicit patterns of activity reflecting aspects of knowledge intrinsic to the representation of the concepts. Although there were no effects of either lexical class or semantic attribute type on recognition memory, robust electrocortical effects indicated both stimulus dimensions had cognitive and neural validity and were engaged by the recognition memory task.

**Figure 3.** Grand average ERPs evoked at 37 scalp sites by abstract, visual, and motor semantic attribute types, collapsed over nouns and verbs. The plots are arranged to resemble their positions on the scalp. Negative is plotted upwards.



This confirms the efficacy of the recognition task in activating the relevant grammatical and semantic aspects of the stimuli, although we cannot determine conclusively whether the observed ERP effects reflect differential processing specifically associated with task employed here, or differential activation of grammatical class and semantic attributes during activation of the words' semantic representations, which would generalize to other paradigms. Further, it should be noted that the following discussion refers to results obtained from nouns and verbs presented in isolation, and it is not clear that the findings would generalize to more complex sentence contexts, which are likely to interact with

and influence the processing associated with the constituent words.

### Noninteracting Effects of Lexical Category and Semantic Attribute Type

While both grammatical class and attribute type dimensions modulated the "P2" and N400 components, the absence of any statistical interaction between these was striking. Interpretation of the absence of any interactions between class and attribute type should be treated with caution, as it remains possible that the lack of an interaction in some way reflects the particular processing

**Table 3.** Summary of Statistically Significant Effects Involving Feature Type Resulting from 50 msec Analyses

Epoch (msec)	Effect	Midline Sites		Lateral Sites	
		F	p/GG	F	p/GG
<i>P2</i>					
250–350	Type	5.60	.006	7.12	.002
300–350	Type × Site			3.64	.006
<i>N400</i>					
350–450	Type	7.36	.001	10.08	.000
	Type × Site	4.24	.007	7.58	.000
450–550	Type	7.88	.001	10.80	.000
	Type × Site	6.95 (2.41)	.000 (.051)	10.73 (6.50)	.000 (.000)
550–750	Type × Site			6.69 (4.79)	.000 (.001)
	Type × Site × Hemi			3.26 (3.36)	.005 (.002)

Degrees of freedom for Type main effects are (2, 58), while for Type × Site and Type × Site × Hemi interactions, the degrees of freedom are (8, 232) for the midline analyses and (30, 870) for the lateral site analyses.  $p = p$  value, GG = Greenhouse–Geisser adjusted significance value. Values in parentheses correspond to effects that were significant after rescaling.

characteristics of the recognition task used here. The observation of reliable modulations of P2 and N400 amplitudes by both variables, however, suggests that the paradigm would also have been sensitive enough to capture any robust interactions between these variables. Furthermore, closer visual inspection of the data indicates that the effects of attribute type for each grammatical class (Figure 4A) and of grammatical class for each attribute type (Figure 4B) on the N400 and P2 components were fairly consistent. Interestingly, there is a tendency (although not supported statistically) for the grammatical class effect on the N400 to be somewhat attenuated for abstract stimuli relative to visual and motor stimuli, and for the attribute effect to be reduced for verbs relative to nouns (both abstract and verb stimuli have been argued to be less highly imageable: see Bird, Howard, & Franklin, 2000). Nonetheless, the pattern of noninteracting and parallel effects reflected in the statistical analyses suggests that both category-based (grammatical class) and attribute-based distinctions define lexico-semantic representation. It is also consistent with the processing equivalence of the semantic feature types across grammatical class. While it has previously been reported that action nouns and action verbs elicit comparable patterns of electrophysiological activity (Pulvermüller, Mohr, et al., 1999), the present data extend this to both “visual” and “abstract” semantic attribute descriptions.

### Lexical Categories and Semantic Attributes Both Modulate “P2” Amplitude

ERP effects of grammatical class have previously been reported in the form of an enhanced centro-frontal

positivity over the epoch 200–230 msec (“P2” component) associated with verb stimuli (Pulvermüller, Lutzenberger, et al., 1999; Pulvermüller, Mohr, et al., 1999; Preissl et al., 1995). In the present study, an enhanced “P2” component elicited by verbs relative to nouns was also observed, although the effect had a somewhat later latency (250–350 msec) and a more posterior focus relative to previously reported modulations of the P2. Consistent with the neuropsychological evidence for selective impairments of these lexical classes, this lexical category effect was shown to arise from distinct neural sources underlying the noun and verb ERPs, although inferences regarding the anatomical loci of the neural sources cannot be made on the basis of the ERP data alone.

Pulvermüller et al. interpreted their modulation of the P2 as reflecting the differential contributions of motor and visual attributes to the semantic representations of verbs and nouns, and they specifically claimed that the anterior distribution of the enhancement of the P2 associated with verbs reflected the recruitment of motor specific processing in frontal cortical regions. The current data cannot easily be accommodated within this theoretical framework, however, as there are several indications that the enhancement of the posterior P2 component associated with verbs is not simply attributable to the higher salience of motoric knowledge: (1) The effect was obtained across three types of verbs, two of which did not have high motor attribute salience (cognition and visual). (2) Comparable enhancements of the P2 component were obtained for verbs, abstract words, and words with high visual attribute salience (relative to nouns and motor attributes, respectively: see below)—motor words were associated with an attenuated posterior P2 component.



which has been shown to be informative about both semantic context and structure (e.g., Kounios, 1996; Kounios & Holcomb, 1992, 1994). Specifically, Kounios et al. have suggested that N400 amplitude to individual words reflects the number of semantic features comprising a concept's representation, assuming a direct correspondence between the number of features and neurones activated (see also Plaut & Shallice, 1993; de Groot, 1989). Within this interpretative framework, nouns elicited a larger N400 because their hierarchically organized semantic structure activated a more extensive and complex network of semantic features than verbs, which have more structural syntactic representations (e.g., Grossman et al., 1996; Miller & Fellbaum, 1991). This account is also consistent with reports that word classes that play a primarily grammatical role in language (e.g., function words) elicit attenuated N400 components relative to content words (Nobre & McCarthy, 1994; see also Neville, Mills, & Lawson, 1992; Van Petten & Kutas, 1991; Kutas, Van Petten, & Besson, 1988). It is less obvious how the differential enhancement of the N400 in response to verbs and nouns presented in isolation can be accounted for by the prevalent proposal that the amplitude of the N400 component indexes the degree to which a lexical item is congruous with (and therefore the ease with which it is integrated into) its semantic context (e.g., Chwilla, Kolk, & Mulder, 2000; Kellenbach & Michie, 1996; Brown & Hagoort, 1993; Brown, Hagoort, & Chwilla, 2000; Holcomb, 1993; Bentin, McCarthy, & Wood, 1985; Rugg, 1985, 1987; Kutas & Hillyard, 1980, 1984, 1989), although both this account and the interpretation based on representational complexity may be seen to suppose that the N400 is attenuated when activation of lexical concepts requires less "effort."

### Temporal Precedence for Motor Attributes

The earliest effect of attribute type was the posterior 250–450 msec divergence of the ERP elicited by motor words from those elicited by both visual and abstract words (Figures 2d and e).<sup>3</sup> While consistent with the cognitive validity of motor attributes in semantic representation, there was no support for motor attributes engaging a distinct cortical source. The temporal precedence of the effect of motor attribute salience implies that motor knowledge is accessed particularly quickly or efficiently, regardless of whether the stimulus is a manipulable object or an action (verb). This is consistent with previous observations that associative-functional attributes are more salient and accessible than visual attributes in the processing of lexical stimuli referring to manmade objects (Laws, Humber, Ramsey, & McCarthy, 1995). Since motor words have both high motor and visual attribute salience, it is interesting that a number of researchers have stressed the importance of strong

interactive connections between visual-perceptual and action-based knowledge for manipulable objects (e.g., Magnie, Ferreira, Giusiano, & Poncet, 1999; Moreaud, Charnallet, & Pellat, 1998; De Renzi & Lucchelli, 1994; Goodale & Milner, 1992; Sirigu et al., 1991; Riddoch, Humphreys, Coltheart, & Funnell, 1988). In this context, the early differential activation for motor words reflects rapid activation due to inputs from multiple interactive sensorimotor sources.

### Visual Attribute Salience and the N400 "Concreteness Effect"

Both visual and motor words elicited greater anterior negativity than abstract words from 300 to 550 msec (Figures 2f and h), while from 550 to 750 msec, this effect became left lateralized (Figures 2g and i). The earlier part of this concreteness effect resembles that reported by Kounios and Holcomb (1994) using only noun stimuli. Our result extends the concreteness effect to verbs, while the similarity between the visual and motor attribute word ERPs indicates that this concreteness effect specifically reflects differences between "abstract" and visual attribute processing—the presence of salient motor attributes did not further influence the amplitude of the effect. This visual attribute specificity indicates the amplitude of the effect is not simply a nonselective index of the amount of activated semantic information (e.g., Kounios & Holcomb, 1994; see also de Groot, 1989).

The concreteness effect showed no evidence of the right hemisphere maximum, which characterized the effect reported by Kounios and Holcomb (1994) (i.e., 300–500 msec) and was taken as evidence that the visual nature of concrete words engages right hemisphere cortical areas (Paivio, 1986) (see Figure 2f and h). Their concreteness effect and its hemispheric asymmetry were more robust when a more explicit concrete-abstract categorization task was used, suggesting that more implicit tasks such as that used here may attenuate these effects. Nonetheless, distinct neural populations contributed to the processing of visual and abstract words in the present study, consistent with the idea that visual semantic attribute processing engages distinct neural substrates (Paivio, 1991). Perhaps more puzzling was the left hemisphere maximum evident anteriorly over the later epoch 550–750 msec (Figures 2g and i), although the latency of this effect suggests that it indexes postlexical processes associated with the recognition memory task.

### Conclusions

The current ERP study examined whether processing differences observed between the lexical categories noun and verb can be best explained by a categorical distinction per se, or by differential contributions from underlying

semantic attributes (abstract, visual, motor). Systematic manipulation of these two dimensions yielded a series of ERP effects for grammatical class and attribute type, which modulated the same components. These results are compatible with lexical–semantic knowledge being organized in a manner that takes account of both category-based (grammatical class) and attribute-based distinctions, and with these types of knowledge being processed over comparable time courses.

## METHODS

### Participants

Thirty students, who were native speakers of Dutch, were paid for their participation in the ERP experiment. There were 21 females and 9 males, with a mean age of 21.6 years (range = 18–29 years). All subjects were right handed as determined by a Dutch translation of the Oldfield Handedness Inventory (Oldfield, 1971), had normal or corrected-to-normal visual acuity, and no known neurological impairments or history of reading problems, as determined by self-report.

### Materials

A large pool of nouns and verbs were each subdivided into three semantic feature type subcategories that differed in the saliency of their visual-perceptual and motor components (Table 4). Abstract nouns and cognition verbs (“abstract” stimuli) are associated with no/few perceptual and no/few motor features; nonmanipulable objects and motion verbs (“visual” stimuli) are associated with clear visual-perceptual features, but no/few motor features; manipulable objects and action

verbs (“motor” stimuli) are highly associated with both visual-perceptual and motor features.

Thirty-five stimuli for each experimental condition were selected on the basis of their visual and motoric associations (Table 5) as determined by having 30 students rate a randomly combined list of the nouns and verbs on both visual and motoric association. Visual association was defined as “how much you associate the word with something you can see (in the outside world).” Motor association was defined as “how much you associate the word with something you can do physically, or something you can perform an action with.” A five-point scale was used for each association rating (1 = *no association*, 5 = *very high association*), and experimental stimuli were selected using the following mean cut-off criteria (see Appendix 1 for stimuli in Dutch):

- Abstract: abstract nouns and cognition verbs:  $\leq 2.5$  on both visual and motoric scales;
- Visual: nonmanipulable nouns and motion verbs:  $\geq 2.5$  on visual scale,  $\leq 2.5$  on motoric scale; and
- Motor: manipulable nouns and action verbs:  $\geq 2.5$  on visual scale,  $\geq 2.5$  on motoric scale.

The conditions were matched on mean word length and written frequency (occurrences per 42 million, CELEX database, Nijmegen; Table 6). Five words from each category were selected as targets for the recognition test, and an additional five words were selected from the original lists as distracters for the recognition test. These were matched to the recognition test target items on visual/motor association ratings, word length, and written frequency (Table 6). No grammatically ambiguous words were included in the stimulus set (see Note 2).

**Table 4.** Description of the Fractionation of Noun and Verb Stimuli into Semantic Feature Type Subcategories, Showing the Relative Saliency of Visual-Perceptual and Motor Attributes ( $\uparrow$  = High Saliency,  $\downarrow$  = Low Saliency)

Word Type	Description	Example	Visual	Motor	Stimulus Type
<i>Nouns</i>					
Abstract	refer to concepts with no physical reality	idea	$\downarrow$	$\downarrow$	abstract
Nonmanipulable	refer to objects with a physical reality, but not associated with a direct human action	numberplate	$\uparrow$	$\downarrow$	visual
Manipulable	refer to objects with a physical reality, and associated with a direct human action	pen	$\uparrow$	$\uparrow$	motor
<i>Verbs</i>					
Cognition	refer to covert intellectual or mental processes without a physical reality	forget	$\downarrow$	$\downarrow$	abstract
Motion	refer to types of visually observable motion of inanimate entities not associated with human motor action	flow	$\uparrow$	$\downarrow$	visual
Action	refer to visually observable actions, and associated with direct human motor action	kick	$\uparrow$	$\uparrow$	motor

**Table 5.** Mean Visual and Motor Associations Ratings (Five-Point Scales) for the Experimental Stimuli for each of the Six Stimulus Categories ( $N = 35$  per Category)

<i>Word Type</i>	<i>Visual Association Ratings</i>	<i>Motor Association Ratings</i>
<i>Abstract</i>		
Abstract nouns	1.58 (0.84)	1.26 (0.50)
Cognition verbs	1.61 (0.80)	1.21 (0.52)
<i>Visual</i>		
Nonmanipulable objects	4.83 (0.46)	1.24 (0.60)
Motion verbs	3.50 (1.12)	1.94 (1.22)
<i>Motor</i>		
Manipulable objects	4.84 (0.46)	3.53 (1.17)
Action verbs	4.08 (0.99)	4.45 (0.77)

Standard deviations are in parentheses.

## Procedure

The stimulus words were presented foveally in light grey uppercase letters (visual angle per letter: vertical =  $0.57^\circ$ , horizontal (mean) =  $0.29^\circ$ ) on a dark background with a viewing distance of 100 cm. The stimuli were presented one at a time in a single block in a pseudorandom order, with the restriction that no more than four words from any one category could occur sequentially. A different pseudorandom order was generated for each subject. Each stimulus word was presented for 500 msec, with an ISI of 2000 msec. During the ISI, two small, vertically aligned fixation dots were presented, which were white for 750 msec, then grey for 1000 msec, and then white again for another 750 msec before the next word was presented. Subjects were instructed to refrain from blinking, except for during the grey fixation interval. A 50-word

practice block preceded the experiment to ensure that blinks were restricted to the grey fixation interval.

Subjects were tested individually in a dimly illuminated, sound-attenuated, and electrically shielded room. Following electrode application, subjects were instructed to read each word silently and attentively, in preparation for a recognition test presented at the end of the testing session. The recognition rather than recall nature of the test was emphasized, and subjects were told that too many words would be presented for a mnemonic strategy to be effective. Instead, attentive reading was suggested as a suitable strategy for maximizing the chance of later recognition. The recognition test followed completion of the experimental run and was comprised of 60 words: five “old” targets (from the experiment) and five “new” distracters (not from the experiment) from each word category. The recognition test utilized response-contingent single-word presentation, with a maximum response time of 20 sec. Subjects classified each word as either “old” (right hand) or “new” (left hand) using two finger-lift buttons. EEG was not recorded during the recognition test.

## ERP Recording

EEG was recorded from 37 scalp sites, using an electrode cap (ElectroCap International). Electrodes were placed at: Fz, Cz, Pz, Poz, Fp1, Fp2, F3, F4, F7, F8, FC3, FC4, FT7, FT8, C3, C4, T7, T8, C3, C4, TP7, TP8, P3, P4, P7, P8, PO3, PO4, PO7, PO8, O1, O2, P9, P10, PO9, PO10, O9, O10 (Sharbrough et al., 1991). Scalp electrodes were referred to electronically linked earlobes. Vertical and horizontal EOGs were recorded via electrodes placed above and below the left eye, and on the outer canthus of each eye, respectively. Electrode impedances were reduced to less than 5 k $\Omega$ . The EEG and EOG recordings were amplified with a 10-sec time constant and a 200-Hz low-pass filter, sampled at 1000 Hz, digitally filtered with a low-pass cut-off frequency of 30 Hz, and reduced on-line to a sample frequency of 100 Hz.

**Table 6.** Mean Written Frequencies and Word Lengths for all Stimulus Categories for Experimental Stimuli, and Targets and Distracters from the Recognition Test

<i>Word Type</i>	<i>Experimental Stimuli</i>		<i>Recognition Test Targets</i>		<i>Recognition Test Distracters</i>	
	<i>Frequency</i>	<i>Word Length</i>	<i>Frequency</i>	<i>Word Length</i>	<i>Frequency</i>	<i>Word Length</i>
Abstract nouns	108.1	7.57	108.6	7.60	105.4	5.80
Nonmanipulable objects	108.8	7.83	110.4	8.40	111.0	8.80
Manipulable objects	107.7	7.91	109.8	7.80	110.4	7.80
Cognition verbs	109.3	7.82	109.8	7.40	109.4	9.00
Motion verbs	108.0	7.86	109.0	7.80	107.6	8.00
Action verbs	107.7	7.86	109.2	8.00	111.8	7.20

## Data Analysis

ERPs were averaged offline. A 900 msec epoch of EEG data was computed separately for each electrode site and each word type and was aligned to a 100-msec prestimulus baseline. Trials were excluded if invalidated by ocular artefact (vertical EOG > 50  $\mu$ V, horizontal EOG > 30  $\mu$ V) or out-of-range artefacts.

Electrode sites were divided into midline (Fz, Cz, Pz, Poz, Oz) and lateral (Fp1, Fp2, F3, F4, F7, F8, FC3, FC4, FT7, FT8, C3, C4, T7, T8, TP7, TP8, P3, P4, P7, P8, PO3, PO4, PO7, PO8, O1, O2, P9, P10, PO9, PO10, O9, O10) sets for analysis. Repeated-measures ANOVAs were carried out on the mean amplitudes of the ERPs for each set of sites with the following factors:

- Midline: 2 levels of grammatical class (“Class” henceforth), 3 levels of semantic feature type (“Type” henceforth), and 5 levels of electrode site (“Site” henceforth).
- Lateral: 2 levels of grammatical class (“Class”), 3 levels of semantic feature type (“Type”), 16 levels of electrode site (“Site”), and 2 levels of hemisphere (“Hemi” henceforth).

Initial exploratory analyses of mean amplitudes over 50 msec windows from 0 to 800 msec poststimulus were employed to investigate the onset and offset times of effects of grammatical class and semantic feature type. Effects lasting 100 msec or more were then analyzed as a single epoch by averaging amplitudes over the range of the effect. The significance criterion used for ANOVAs performed on epochs > 50 msec was  $p < .05$ , however, a significance criterion of  $p < .01$  was employed for the analysis of 50 msec epochs to correct for the increased likelihood of Type I errors associated with the exploratory analyses. The degrees of freedom were adjusted, when appropriate, by the Greenhouse–Geisser (1959) procedure to avoid Type I errors through violation of the assumption of sphericity (Vasey & Thayer, 1987). All significant interactions arising from the ANOVAs involving interactions with a distributional variable (Site or Hemi) were reanalyzed after normalization of the data according to the vector method described by McCarthy and Wood (1985). This procedure corrects for the possibility that an apparent distributional difference between (nondistributional) variables of interest may be due to multiplicative source activation strength differences, rather than truly additive effects reflecting at least partially independent underlying neural populations, as is assumed by the ANOVA model. Results based on normalized data will only be reported if the effect of interest remained significant.

The recognition accuracy data were analyzed using a repeated-measures ANOVA to investigate grammatical class and semantic feature type effects on correct target responses and false alarms.

## APPENDIX 1

<i>Abstract</i>	<i>Nouns</i>	
	<i>Visual (Nonmanipulable Objects)</i>	<i>Motor (Manipulable Objects)</i>
adoratie	balkon	afwasborstel
banvloek	batterij	blikopener
bekomst	biels	deegroller
bemoeienis	boiler	dweil
bijzaak	bushalte	flesopener
blaam	dakgoot	frisbee
bront	gootsteen	gaspedaal
doem	hoogslaper	gieter
eendracht	kalender	hamer
foefje	kerstbal	jojo
gelag	kozijn	kaasschaaf
geschil	kroonluchter	kam
intelt	lichtboei	kleurpotlood
jargon	nummerbord	lepel
klemtoon	parel	nietmachine
laster	piramide	pincet
list	plint	rits
moederschap	put	schaar
morfologie	radiator	schuurpapier
motie	raket	spade
onbegrip	regenpijp	stoffer
prioriteit	schutting	stofzuiger
profijt	schuur	strijkijzer
reorganisatie	spoorboom	tandenborstel
scherts	stapelbed	theedoek
schuldgevoel	steiger	theelepels
thema	stellage	toetsenbord
vaderschap	stoplicht	trapper
vergeving	tribune	typemachine
verzinsel	vitrage	vijl
vete	vluchtheuvel	viltstift
voorproef	vuurtoren	vork
weerklink	wandklok	vulpen
wilskracht	windmolen	washandje
zede	windwijzer	zakmes

<i>Verbs</i>		
<i>Abstract (Cognition)</i>	<i>Visual (Motion)</i>	<i>Motor (Action)</i>
aanvoelen	afdrijven	afkloppen
afwijzen	dalen	afwassen
bedoelen	deinen	bijten
bedroeven	dobberen	borstelen
begeren	drijven	breien
benijden	druipen	graaien
beramen	druppelen	grabbelen
berusten	dwarrelen	hijzen
beseffen	exploderen	jongleren
deduceren	groeien	kietelen
goedkeuren	instorten	knijpen
gunnen	kabbelen	maaïen
haten	klotsen	omhelzen
hekelen	knappen	oppakken
hunkeren	krimpen	opstapelen
imponeren	neerdalen	pellén
kniezen	neerkomen	schilderen
mijmeren	neerstorten	schoffelen
nadenken	opdoemen	schrapen
opletten	opstijgen	schrobben
overdenken	overhellen	sjoelen
peinzen	overwaaien	snijden
piekeren	rijzen	snoeien
rouwen	sijpelen	spitten
smachten	slijten	stampen
snappen	slinken	strelen
spijten	slippen	strijken
tolereren	stijgen	tennissen
verachten	stuiven	timmeren
verbazen	verrijzen	uitwringen
verdenken	vloeien	vastgrijpen
vergeven	wegspoelen	wassen
verzinnen	zinken	werpen
vrezen	zwellen	worstelen
walgen	zweven	wroeten

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## Notes

1. Although not explicitly reported by Coltheart et al. (1998), the interactions between attribute type and electrode site did survive rescaling (McCarthy & Wood, 1985), enabling this interpretation (P. Michie, personal communication).
2. The experiment was in Dutch, in which many nouns and verbs are unambiguous with regard to their grammatical class. Only class-unambiguous nouns and verbs were included as stimuli in the current study.
3. In the absence of any obvious commonality between abstract and visual words, we assume that it is the differential processing of the motor words that results in the differential modulation of the posterior ‘‘P2.’’

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