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Event-related brain potentials evoked by verbs and nouns in a primed lexical decision task

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Abstract

We investigated whether verbs and nouns evoke comparable behavioral and N400 effects in a primed lexical decision task. Twenty-nine students were tested, 13 in a pilot study in which only response times and error rates were collected and 16 in a study in which ERPs were recorded from 124 scalp electrodes. Stimuli were noun–noun and verb–verb pairs with the targets bearing either a strong, a moderate, or no semantic association to the prime or being a pseudoword. Behavioral data revealed comparable priming effects for both word categories. These proved to be independent from the SOA (250 and 800 ms) and they followed the well-known pattern of decreasing response times and error rates with increasing relatedness between target and prime. ERPs revealed pronounced N400 effects for both word categories with a larger amplitude for noun than for verb pairs. A systematic analysis of topographic differences between noun- and verb-evoked ERPs and N400 effects, respectively, gave no convincing support to the hypothesis that the two word categories activate distinct neuronal networks.

Descriptors: Semantic priming, Verbs, Nouns, Lexical decision, N400, ERP

Meyer and Schvaneveldt (1971) were the first who showed that words are identified faster if they are preceded by other words related in meaning. This so-called semantic priming effect has become a well-established finding that can provide insight into how knowledge about words is mentally represented (for an overview, see Moss & Gaskell, 1999, or Neely, 1991). Originally, it was assumed that semantic priming depends exclusively on automatic activation spread in the "semantic lexicon." However, several findings suggest that the effect as such has most likely more than one functional cause. Depending on the particular experimental setup (type of task, interstimulus interval, masking, etc.) both automatic spread of activation (Collins & Loftus, 1975) and strategic processes of semantic integration (Neely, 1977; Posner & Snyder, 1975) seem to contribute. Moreover, recent work of Drews and Zwitserlood (1995) and Stolz and Besner (1998) has shown that the cause of priming effects is not necessarily a spread of activation within the semantic representation level alone, but that it can also be due to activation spread within more "peripheral" levels of representation (orthography, phonology, morphology). Irrespective of these qualifications, the basic effect can be taken as empirical support for the notion that knowledge about words is represented in an interconnected network of nodes representing individual concepts or concept features. When such a node becomes active, activation spreads to other related nodes, preparing the system to identify related concepts (Anderson, 1983; Masson, 1995).

The behavioral priming effect is mirrored by an electrophysiological sign, the N400 effect of the event-related brain potential (ERP). The N400 effect is a negative deflection in the ERP that peaks around 400 ms after onset of unprimed word stimuli and that has a maximum amplitude over centroparietal brain areas. Many studies (Federmeier & Kutas, 1999; Kutas & Hillyard, 1980, 1983, 1984; Kutas, Van Petten, & Besson, 1988) have demonstrated that contextually unexpected words in a sentence elicit an N400 effect ("He took his coffee with milk and *mustard*" versus ". . . and *sugar*"). Further studies revealed that the amplitude of the N400 effect depends on the word position within a sentence, in that contextually unprimed words appearing at the beginning of a sentence elicit larger N400 amplitudes than words presented later (Kutas & Van Petten, 1988; Van Petten & Kutas, 1990). Moreover, others have shown that the N400 effect is not restricted to words presented in a sentence context. When presenting lists of isolated words or word pairs in a lexical decision paradigm, the N400 effect proved to be significantly larger for words that had not been preceded by a related word (e.g., Anderson & Holcomb, 1995; Bentin, McCarthy, & Wood, 1985; Chwilla, 1996; Holcomb & Neville, 1990). Findings such as these suggest that the N400 may reflect the degree to which a word is expected within the currently prevailing semantic context. If the perceived information does not fit into the primed context, additional activity within the semantic network is required in order to achieve a coherent semantic interpretation. To date, it is not clear whether this additional activation is mainly due to automatic or to strategic factors. Current evidence with respect to this question is controversial (see Brown & Hagoort,

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1993, versus Kiefer & Spitzer, 2000; Rolke, Heil, Streb, & Hennighausen, 2001). Nevertheless, it seems most likely that the amplitude of the N400 effect reflects the amount of additional activation that is necessary to process a just encountered word (Rösler & Hahne, 1992): The more a representation is primed already, the less additional activation is necessary and the smaller will be the N400.

Given that the N400 effect reflects additional activation processes within the word representation network, it could be assumed that the maximum effect has a distinct topography depending on which partition of the lexicon is activated. Different types of content words are most likely linked to different aspects of the world and, therefore, they should be represented by distinct memory partitions. It has been suggested, for example, that concrete nouns are closely linked to perceptual entities whereas motion verbs are linked to motor programs (Pulvermüller, 1999). This conjecture is also nourished by neuropsychological evidence showing that more anteriorly versus more posteriorly located lesions of the cortex can selectively impair noun and verb knowledge (e.g. Chen & Bates, 1998; Damasio & Tranel, 1993). Accordingly, the N400 effect triggered by nouns and verbs in a typical priming situation should have a distinct topography, that is, a more anterior maximum for verbs and a more posterior maximum for nouns.

A first approach to test this hypothesis was made by Gomes, Ritter, Tartter, Vaughan, and Rosen (1997), who presented in a delayed decision task three stimuli in succession, a prime, an associated or unassociated target, and a probe. The participants had to decide whether the probe was a repetition of one of the two preceding words. The first two words could be either noun/noun or noun/verb pairs, and the N400 effect was determined for the two different types of targets. This study, however, failed to show any topographic difference between the noun and the verb N400 effect. Possible reasons for this failure are manifold: It could be due to the relatively long SOA (1,150 ms) that may have induced a strategic priming effect rather than an automatic spread of activation. Further, as nouns were used as primes in any case, the system may have expected nouns and verbs as targets equally likely. If so, a topographic difference between nouns and verbs seems unlikely, because the verb partition and the noun partition of the lexicon will have been activated with equal strength. Finally, the task was different from standard lexical decision or naming procedures. Thus, it could have induced additional decision-related effects that may have camouflaged priming-related ERP effects.

To circumvent these problems, we pursued a different approach in the present study. We compared verb/verb and noun/noun prime-target pairs in a standard lexical decision task. Thus, a verb prime predicted with certainty a verb target and a noun prime a noun target. Therefore, a verb prime should preferably trigger the spread of activation within that memory partition that represents knowledge about verbs and a noun within that partition that represents knowledge about nouns. Moreover, to give automatic spread of activation a better chance, we used a short SOA of 250 ms. Finally, to test for the scope of a possible verb-elicited N400 effect, we realized associations of different strength. For noun/noun pairs, it has been observed that the N400 effect depends on the degree of associative overlap between prime and target. The greater the associative overlap, the smaller is the amplitude of the N400 effect. For example, the strongest association to *bread* may be *butter*. Compared to this target, an unrelated target, for example, *shoe*, will evoke a strong N400 effect, and a target that is partially related to the highly associated target, for example, *milk* or *cheese*, will evoke an N400 effect, too, but with a smaller amplitude (for detailed evidence, see Federmeier & Kutas, 1999; Kutas & Hillyard, 1984; and for an equivalent effect in the domain of arithmetic knowledge, Niedeggen & Rösler, 1999). We expect a similar graded variation of the N400 effect for verb targets that bear either a strong or a moderate associative strength to a verb prime.

One may be skeptical that reliable priming effects can be observed between verb pairs at all, because the most likely association to a verb is not paradigmatic but syntagmatic, that is, in a free association task, a verb triggers most likely not a synonymous verb but a noun being one of its syntactic arguments (e.g., cook—meal, or repair—pants). However, Zwitserlood, Drews, Bolwiender, and Neuwinger (1996) reported a set of studies in which they observed reliable priming effects for verb/verb pairs. On the basis of these findings, they concluded that verbs that denote similar actions, as, for example, *cook—bake* or *mend—repair*, are directly associated in the lexicon and activation will spread from one verb to another verb that has a similar meaning. To test whether such an activation spread takes place between verb pairs at all, we first ran a pilot study in which only behavioral data were collected.

To summarize the plan and the objective of the study: We investigated behavioral and electrophysiological priming effects in a lexical decision task (LDT) with verb/verb and noun/noun pairs, and we expected topographic differences for the N400 effect related to verb and noun targets. Further, we intended to show that both noun and verb targets evoke an N400 effect whose amplitude varies with the associative strength between target and prime. Moreover, the design also allows for testing of ERP effects evoked by nouns and verbs as such, that is, those evoked by the primes and those evoked by the targets irrespective of their relatedness. The respective ERPs (overall averages of verb and noun primes and of verb and noun targets) were also checked for systematic topographic differences, and we expected, as for the N400, a more anterior maximum for verbs and a more posterior maximum for nouns.

Methods

Subjects

Twenty-nine students of the University of Marburg participated (11 male/18 female). Thirteen took part in the pilot study and the remaining 16 in the ERP study. They received either course credit points or a monetary compensation for each experimental hour. Mean age was 24,7 years (range 19–32). All participants were right-handers, they were native speakers of German and none of them had any experience with a similar experiment. Data of 15 participants of the ERP study were available for the analysis of behavioral effects and of 13 for the analysis of ERP effects. Data of the other 1 and 3 participants, respectively, had to be discarded because of equipment failure, recording artifacts, or too many errors.

Material

Three lists of 121 verb–verb and 121 noun–noun pairs were prepared according to the following procedure: Semantically strong and moderately related word pairs were constructed by the use of a German dictionary of synonyms (Radszuweit & Spalier, 1992). For strongly related pairs, for instance, verb pairs as *KEHREN–FEGEN* (transl. *SWEEP–DUST*) and noun pairs as *ZEITSCHRIFT–MAGAZIN* (*NEWSPAPER–MAGAZINE*), the two most closely related synonyms were selected. For moderately related pairs, we took the first word and selected as second word a less suitable description for the same action or object, for example, *KEHREN–SÄUBERN* (*SWEEP–CLEAN*) and *ZEITSCHRIFT–TEXT* (*NEWSPAPER–TEXT*). The third group of items comprised unrelated word pairs that were formed by selecting a completely unrelated target, for example, *KEHREN–STEMPELN* (*SWEEP–STAMP*) and *ZEITSCHRIFT–KAUFMANN* (*NEWSPAPER–MERCHANT*).[1]

The strongly, moderately, and not related targets selected for the same prime were matched for frequency of occurrence, in that they did not deviate more than 150 entries per million from each other (CELEX, 1995). The word length was almost equivalent for all three lists (average seven letters). The word pairs were presented to 15 subjects who were asked to judge the semantic similarity of each word pair on a 5-point cale ranging from "sehr ähnlich" (*very similar*) to "überhaupt nicht ähnlich" (*not similar at all*). According to the criterions of variance and distance, we selected the best fitting pairs and discarded 21 verb and 21 noun pairs. Table 1 summarizes for the selected word pairs and each word category the mean similarity ratings and the mean target frequency. In total, there were 100 word pairs in each condition. ANOVAs revealed no significant difference for word frequency but a highly significant difference for the similarity ratings.

On selecting the stimuli, we tried to include mostly verbs that trigger action associations and nouns that trigger vivid object associations. To validate this presupposition we recruited another sample of 12 subjects who rated all words on a 5-point scale with the anchors "1 = strong visual-perceptual associations" and "5 = strong motoric associations." This rating provided mean values of 2.16 for nouns and 4.17 for verbs with a highly significant t test across subjects, $t(11) = 8.126$, $p < .001$. Thus, on average, the nouns triggered more visual perceptual associations than the verbs and the verbs triggered more motoric associations than the nouns. Thus the prerequisite that the two word categories are linked to distinct types of associations is met by the stimulus material.

Finally, three other sets of items were constructed by pairing each of the 200 selected primes with three different pseudowords, for example, *KEHREN–DEUSEN* and *ZEITSCHRIFT–ENDIAN*. The pseudowords were derived from common words by replacing at least one letter with another letter in such a way that it did not violate the orthographic or phonologic rules of German. Thus, the final set of stimuli comprised 600 item pairs for the verb condition and 600 item pairs for the noun condition. Within each set, each prime was repeated six times and followed by either a closely related, a moderately related, an unrelated target word, or a pseudoword (three times).

Table 1. *Characteristics of the Used Target Words. Means (± Standard Deviation) of the Similarity Ratings of Prime and Target on a 5-Point Scale and of Word Frequency (Occurrence/Million)*

Target	Similarity rating	Word frequency
Nouns		
Unrelated	1.18 ± 0.53	73.23 ± 132.66
Moderately related	3.17 ± 1.27	81.19 ± 134.98
Strongly related	4.38 ± 0.89	65.29 ± 125.00
Verbs		
Unrelated	1.24 ± 0.59	74.89 ± 113.24
Moderately related	3.05 ± 1.21	68.04 ± 80.62
Strongly related	4.10 ± 1.00	70.32 ± 88.18

Procedure

Participants sat in an electrically shielded, dimly lit room facing a computer screen (ATARI SM 124, refresh rate 70 Hz), which was positioned at eye level 0.7 m in front of the head. A trial started with a frame in light gray presented in the center of the screen. The frame served as fixation aid and extended 5 cm horizontally and 2 cm vertically. The two words of each trial were presented in black uppercase letters with a vertical size of 0.5 cm centered within the frame. Each word was shown for 200 ms. The prime always appeared 500 ms after frame onset. In the pilot study, one half of the target stimuli were presented with an ISI of 50 ms (SOA 250 ms) and the other half with an ISI of 600 ms (SOA 800 ms). In the ERP study, all word pairs had an ISI of 50 ms, that is, an SOA of 250 ms. The frame remained on the screen during the presentation of the prime and target and for another 1 s after target onset. The next trial was started after a variable intertrial interval (ITI) ranging from 3 to 3.5 s.

Participants were instructed to decide whether the target stimulus was a real word of German or not. They were told to respond as quickly and accurately as possible. Index and middle fingers of the right hand rested in two cavities equipped with light gates. An upper movement of a finger opened the gate and the reaction time was recorded. The finger used for each response was counterbalanced across subjects. Participants had to decide within an interval of 1 s after target onset. Delayed and incorrect responses were fed back.

All word pairs were presented in random order with the restriction that those having the same prime were separated by at least 50 trials in between. A fresh trial sequence was created for each subject by a computer program. Trials were presented in blocks of 40 with short (minimum 20 s) breaks between them.

EEG Recording, Artifact Handling, and Signal Extraction

The EEG was recorded from 124 electrodes using a cap with AgAgCl inserts. The horizontal and vertical EOG was monitored with appropriate electrode pairs. Prior to electrode fixing, individual scalp sites were cleaned and abraded through holes in the cap designed to fix the electrodes. Electrodes were fixed on the cap after injection of a conduction gel. All scalp electrodes were referenced to the nosetip. Impedances of all electrodes were kept below 8 kOhm. Four sets of 32-channel amplifier (SYNAMPS, NeuroScan) were used for EOG and EEG recording. Band pass was set from DC to 40 Hz and the sampling rate was 250 Hz. An ATARI Mega ST2 computer controlled the stimulus presentation, and the electrophysiological data collection was done by NeuroScan software Acquire. Prior to the beginning of each experimental block, a DC reset was initiated automatically.

All trials were inspected by one of the experimenters. Trials contaminated by artifacts, that is, amplitudes larger than $\pm 125\ \mu V$, were rejected. Epochs with eye blinks were detected by a wavelet analysis and corrected by a linear interpolation. DC drift artifacts

[1]All English translations are literal and they do not necessarily reflect the same associative strength as the German word pairs. Moreover, we selected only words that could be clearly recognized as verbs or as nouns by their word form. For example, in English *stamp* can be a noun or a verb, but in German the related verb to *Stempel* is *stempeln*, that is, it has a different morphology. In German, nouns start with an upper-case letter and verbs with a lower-case letter. To avoid the word category being revealed by the initial letter alone all targets were presented in upper-case letters only.

were corrected according to a method suggested by Hennighausen, Heil, and Rösler (1993). From the edited set of raw data, ERPs were extracted by averaging single trials separately for subjects, electrodes, and experimental conditions. Only trials with correct answers were used for the ERP average.

Dependent Variables and Statistical Analysis

Error rate and mean response times were determined for the experimental conditions relatedness and word category and, in the pilot study, for the two SOAs. Repeated measurement ANOVAs were calculated to analyze the behavioral data.

For the statistical analysis of the EEG data, we combined the signals of three and four electrodes according to Figure 1 into 19 electrode clusters. By computing the average signal of these clusters, we approximated the key positions of the 10-20 system and of two interpolated locations labeled Broca-left (Bl) and Broca-right (Br). Bl and Br were defined as in previous studies by us and others (e.g., Friederici, Hahne, & Mecklinger, 1996; Rösler, Pechmann, Streb, Röder, & Hennighausen, 1998) and are defined as crossing points of the lines connecting Fz-T3/F7-Cz and Fz-T4/F8-Cz. Bl is close to Broca's area, although it might not be located exactly above it. This procedure was used to reduce the number of electrode levels in the ANOVA design and to avoid significant results that are simply due to a large number of degrees of freedom (protection against falsely accepting H1). However, as the expected topographic differences might be very subtle, we also ran ANOVAs in which factor electrode comprised all 124 recording points to increases the sensitivity of the test. Average voltage amplitudes were computed for consecutive intervals of 30 ms length (seven sampling points). Compared to single-peak measures or the average amplitude of one broader time window, such narrow time slices increase the sensitivity to detecting differences between conditions and topographies, for instance, if these are restricted to the rising or the falling flank of a peak (e.g., Niedeggen, Rösler, & Jost, 1999). To isolate the influence of prestimulus baseline differences, the recorded potentials were referenced to a baseline of 100 ms length preceding word onset. Topographic maps were based on the original 124 recording points.

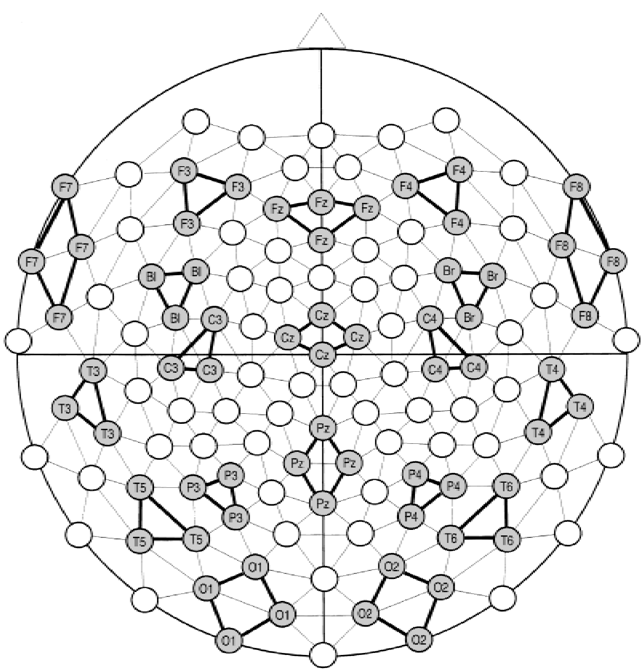

Figure 1. Diagram of the 124 channel locations on the cap. The electrode clusters used for the statistical analyses are marked by gray shading.

To avoid an increase of the likelihood of type-I errors, significant results were considered for interpretation only if they fulfilled the hierarchical constraints described by Rösler, Friederici, Pütz, and Hahne (1993). That is, first an overall ANOVA was run with factor combination Subject $\times$ Experimental Factor(s) $\times$ Electrode Cluster $\times$ Time Epoch (experimental factors could be "word category," "relatedness," or both). Given that the superordinate ANOVA provided significant interactions of the experimental factors with factors Electrode Cluster and Time Epoch, we then ran subordinate ANOVAs for each of the time epochs which considered the factor combination Subject $\times$ Experimental Factor(s) $\times$ Electrode Cluster. In a third step, the effects of the experimental variables were tested separately at each electrode cluster and for each measurement epoch with "local" ANOVAs, provided that the superordinate interactions with factor Electrode Cluster had proved to be reliable. All factors, except Subjects were defined as repeated measures. Probabilities of observed F ratios were adjusted according to the formulas of Huynh and Feldt (1976) and the corresponding ϵ values are presented. Topographic differences between noun- and verb-evoked ERPs and the N400 effects of both word categories were tested by means of standardized z scores, that is, amplitude measures were standardized across all electrodes to eliminate overall amplitude and variance differences between conditions (see McCarthy & Wood, 1985).

Results

Behavioral Data

Pilot Study

Response time. An ANOVA based on word targets only (i.e., excluding pseudowords) revealed significant main effects for Relatedness, $F(2,24) = 51.05$, $p = .0001$, $\epsilon = 1.00$, and Word Category, $F(1,12) = 84.01$, $p < .0001$, $\epsilon = .76$, and a significant interaction Relatedness $\times$ Word Category, $F(2,24) = 9.32$, $p = .0013$, $\epsilon = .95$. Surprisingly, SOA did not affect response times. Neither the main effect nor the interactions with any of the other factors was reliable. Therefore, data were collapsed across both levels of SOA in Table 2. Response times to verb targets were, on the average, 30 ms slower than to noun targets and response time decreased with increasing relatedness of prime and target. As indicated by the significant interaction, the priming effect was more pronounced for strongly related nouns (-44 ms) than for strongly related verbs (-28 ms).

Error rate. Response accuracy, too, differed between conditions (Table 2). The main effect Relatedness was highly significant, $F(2,24) = 26.92$, $p = .0001$, $\epsilon = .68$. Subsequent comparisons showed that subjects committed most of the errors with unrelated and least with strongly related targets. Moderately related targets were in between. Factor Relatedness interacted significantly with factor SOA, $F(2,24) = 6.85$, $p = .0045$, $\epsilon = .99$. Post hoc analyses revealed that participants committed more errors with a short SOA in case of unrelated targets whereas for moderately and strongly related targets, the error rate was about the same size for both short and long SOAs. There was also a main effect Word Category, $F(1,12) = 45.33$, $p = .0001$, $\epsilon = .99$, indicating that the error rate for verbs was significantly higher than for nouns.

Table 2. *Reaction Time, Size of the Priming Effect, and Error Rate for the Different Priming Conditions of the Pilot and the ERP Study (Mean Values in Milliseconds and Percent, ± Standard Deviation).*

Target	Noun RT	Noun Priming effect	Noun Error rate	Verb RT	Verb Priming effect	Verb Error rate
Pilot Study (SOA 250 and 800)						
Pseudoword	719 ± 120		8 ± 27	732 ± 120		9 ± 29
Unrelated	676 ± 127		8 ± 27	700 ± 134		13 ± 34
Moderately related	657 ± 126	−19	5 ± 23	681 ± 130	−19	8 ± 28
Strongly related	632 ± 113	−44	3 ± 17	672 ± 126	−28	7 ± 25
ERP Study (SOA 250)						
Pseudoword	755 ± 126		14 ± 35	762 ± 125		17 ± 38
Unrelated	693 ± 134		16 ± 37	719 ± 141		21 ± 41
Moderately related	668 ± 135	−25	11 ± 31	699 ± 136	−20	16 ± 37
Strongly related	637 ± 125	−56	6 ± 23	677 ± 132	−42	12 ± 33

Note: Data of the pilot study are averaged over the two SOAs.

ERP Study

Response time. All effects observed in the pilot study for the short SOA were replicated in the ERP study. Again there were significant main effects Relatedness, $F(2,28) = 68.09$, $p = .0001$, $\epsilon = .89$, and Word Category, $F(1,14) = 140.19$, $p < .0001$, and a significant interaction Relatedness $\times$ Word Category, $F(2,28) = 9.14$, $p = .0017$. For both word categories, the priming effect was about twice as large for strongly than for moderately related items, and the interaction indicates that the priming effect for strongly related targets was somewhat more pronounced in the noun than in the verb condition. The main effect Word Category substantiates the observation that verb targets were, in general, processed slower than nouns (mean diff $RT = 32$ ms).

Error rate. Again, the effects of the pilot study were replicated, that is, there were significant main effects Relatedness, $F(2,28) = 30.55$, $p = .0001$, $\epsilon = .80$, and Word Category, $F(1,14) = 43.26$, $p < .0001$, but no interaction.

The similarity of the effect patterns of response time and error rate in the pilot as well as in the ERP study excludes that there was a speed–accuracy trade-off.

ERP Data

Primes

Figure 2 shows the grand averages of the primes separately for the two word categories. The two curves start to deviate from each other at about 90 ms after word onset with nouns being slightly more negative over central scalp sites than verbs. ANOVAs run with the unstandardized amplitudes revealed significant main effects Word Category for time epochs 90–150 ms after word onset, $\max F(1,12) = 14.74$, $p = .0024$; $\min F(1,12) = 3.24$, $p = .0970$, and significant interactions Word Category $\times$ Electrode Cluster for time epochs 90–120 ms, $F(18,216) = 2.13$, $p = .0474$, $\epsilon = .40$, and 150–180 ms after word onset, $F(18,216) = 2.13$, $p = .0406$, $\epsilon = .44$. The difference maps computed from the raw scores show that nouns evoked a more pronounced negativity over left anterior scalp sites in the early time window (90–120 ms) and over posterior sites in the later time window (150–180 ms). ANOVAs with factors Word Category and Electrode Cluster were also run for these two time windows with standardized z scores. These analyses gave no evidence for a genuine topographic difference between the two types of primes ($p(F) > .25$ in any case), that is, the difference observed in the raw score plot is most likely due to an amplitude modulation of one and the same generator. This result is

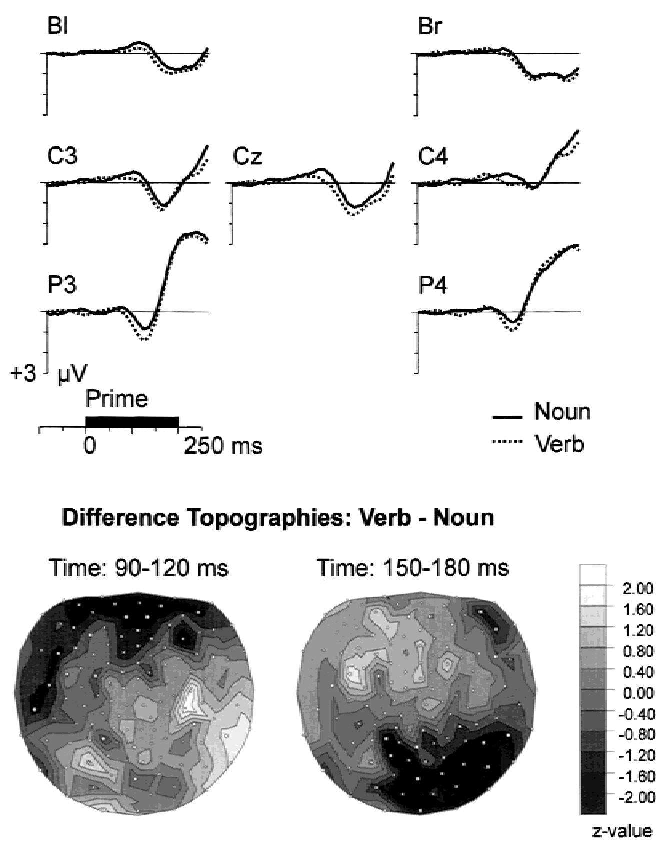

Figure 2. Grand average ERPs elicited by verb and noun primes. The top part shows the voltage time plots at a selected set of electrodes (negativity is up in this and the following figures). Below are the topographic maps of the difference amplitudes between noun–verb ERPs for time windows 90–120 ms and 150–180 ms. The amplitude differences between the two word categories disappear if the ERPs are z-standardized across electrodes (see text).

confirmed if all 124 electrodes are considered for the test (epoch 90–120 ms: $F[1,123] = 1.24$, $p = .2830$, $\epsilon = .07$; epoch 150–180 ms: $F[1,123] = .94$, $p = .4606$, $\epsilon = .04$).

Targets

Priming effects within each word category. The grand average ERPs are plotted in Figure 3 (top: nouns; bottom: verbs). The three target conditions (strongly related, moderately related, and unrelated) are superimposed. The waveforms of the nouns reveal the well-known pattern in that there is a prominent central/parietal positive peak around 500 ms, which becomes increasingly more negative with decreasing relatedness between prime and target. The waveforms of verbs show a comparable pattern, although the positivity evoked by strongly related targets is smaller for verbs than for nouns and the negative going effect due to factor Relatedness is, by and large, restricted to unrelated targets only. Moderately related verbs differ hardly at all from strongly related verbs. The N400 effect, that is, the difference between unrelated and strongly related targets and moderately and strongly related targets, respectively, is shown in Figure 4 (top: nouns; bottom: verbs). For nouns, the N400 effect is substantial for both moderately related and unrelated targets and smaller in size for the former than for the latter. For verbs, an N400

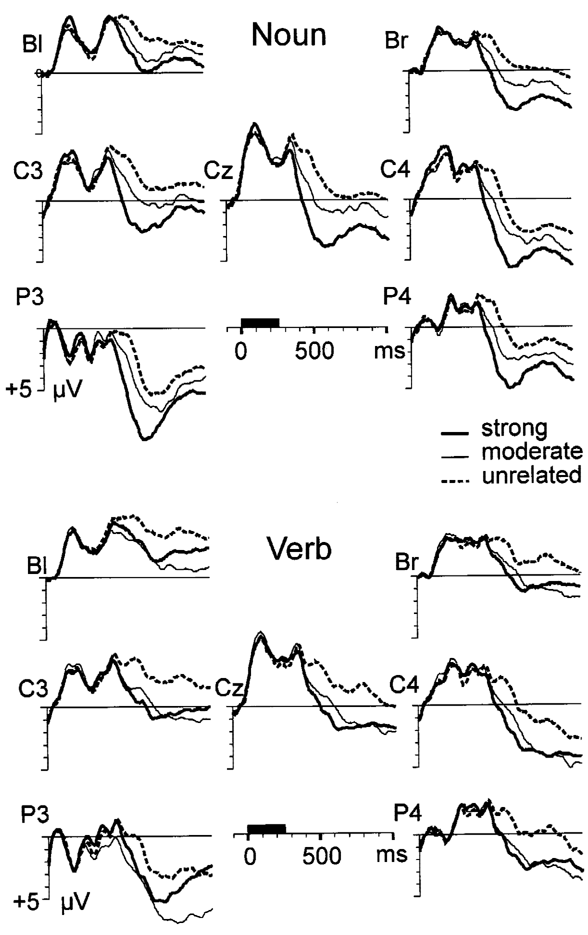

Figure 3. Grand average ERPs elicited by the target stimuli following either strongly, moderately, or unrelated primes. Top: noun targets; bottom: verb targets. A substantial amplitude difference between strongly related and unrelated targets around 400 ms is present for both types of words. The traces are aligned with respect to a 100-ms-long prestimulus baseline.

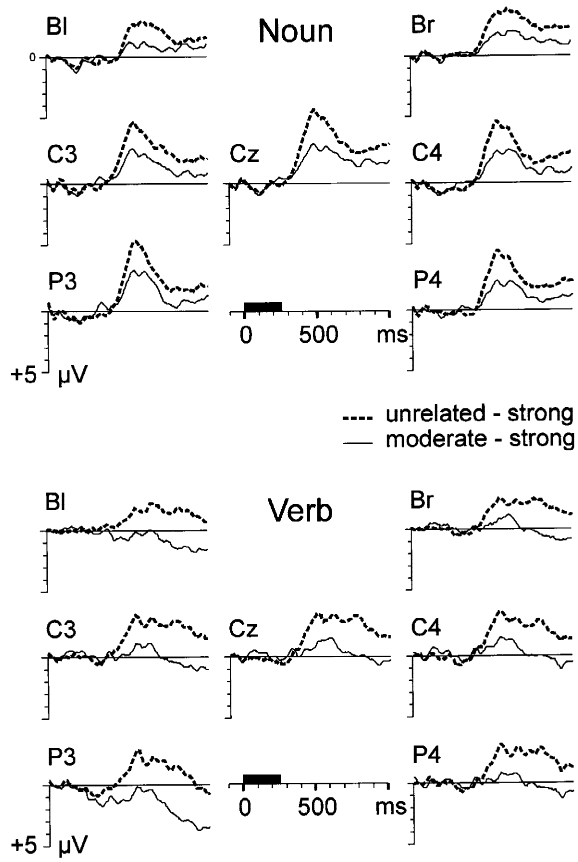

Figure 4. Grand average difference ERPs showing the N400 net effect for noun targets (top) and verb targets (bottom). In each figure, the difference waves for "unrelated–strongly related" and "moderately–strongly related targets" are superimposed. Relative negativity is up, indicating that the less associated target evoked a stronger negative-going amplitude.

effect is only present and statistically significant for unrelated targets. Moreover, the maximum N400 amplitude for unrelated verbs is about the same size as that for moderately related nouns.

These observations are supported by the statistical analysis: The main effect Relatedness was higly significant for both word categories and all consecutive time epochs between 390 and 720 ms, range of F rations for nouns, $\max F(2,24) = 14.97$, $p = .0002$, $\epsilon = .84$; $\min F(2,24) = 4.15$, $p = .0284$, $\epsilon = 1.00$, and verbs, $\max F(2,24) = 15.37$, $p = .0005$, $\epsilon = .70$; $\min F(2,24) = 4.32$, $p = .0333$, $\epsilon = .84$. Further analyses revealed that unrelated targets evoked a significantly larger N400 effect when compared to moderately or strongly related targets, and moderately related targets evoked a larger N400 effect than strongly related targets. This pattern of amplitude differences proved significant for both word categories and for at least two time epochs (e.g., moderately related verbs differed only slightly from strongly related verbs (Figures 3 and 4), but the effect was significant between 540 and 600 ms). There was also a significant interaction Electrode Cluster $\times$ Relatedness in the time window from 390 to 630 ms, $\max F(36,432) = 6.23$, $p = .0001$, $\epsilon = .42$; $\min F(36,432) = 2.43$, $p = .0076$, $\epsilon = .32$, giving evidence that the N400 effect was most prominent at centroparietal clusters.

Differences between word categories. Figure 5 shows the superposition of the average noun and verb ERP, that is, each ERP is

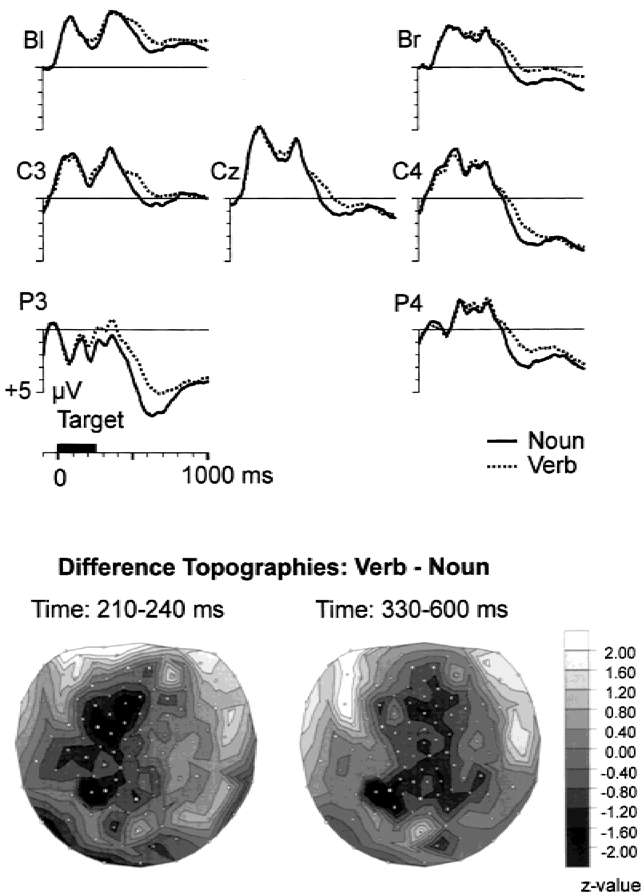

Figure 5. Grand average ERPs evoked by the two types of targets averaged over subjects and all three levels of relatedness, that is, the ERPs represent the average waveforms for nouns and verbs at a selected set of electrodes. Below are the topographic maps of the difference scores between verbs and nouns for two time windows. These difference maps show the genuine topographic difference after z-standardization, that is, after eliminating amplitude and variance differences. According to these topographies, verbs evoked a more negative potential than nouns over the left hemisphere at frontocentral electrodes between 210–240 ms and 360–600 ms. These differences could be due either to processing effects that are specific to activation processes in distinct memory partitions or, more likely, to differences in the speed of response preparation (see text).

averaged over all three levels of relatedness. The time course of the two ERPs is clearly different: Between about 300 and 1,000 ms after word onset, ERPs to verbs are substantially more negative than to nouns. ANOVAs with the raw scores provide significant main effects of factor Word Category between 480 and 660 ms and significant interactions Word Category × Electrode Clusters for the time epochs 30–90 ms, 330–390 ms, 450–630 ms, and 750–900 ms (range of significant F ratios: max$F[18,216] = 3.45$, $p = .0034, \epsilon = .37$; min$F[36,432] = 1.88$, $p = .0871$, $\epsilon = .37$). T tests for consecutive time slices and electrodes disclose that verbs are more negative than nouns within the respective time windows at almost all electrodes.

Analyses with standardized z scores signaled significant interactions Word Category × Electrode Cluster for the time windows 210–240 ms, $F(18,216) = 2.90$, $p = .0211$, $\epsilon = .28$, and 360–600 ms, max$F(18,216) = 3.01$, $p = .0037$, $\epsilon = .48$; min$F(18,216) = 1.79$, $p = .0726$, $\epsilon = .54$. These interactions suggest a genuine topographic difference between noun and verb targets. The topographic maps of the difference amplitudes verbERP(z)–nounERP(z) within these time epochs are also shown in Figure 5. They disclose that verbs are relatively more negative than nouns at left frontal to parietal scalp sites. This is confirmed by consecutive t tests that signal significant topographic differences within the time windows at F7, Fz, F8, Bl, C3, Cz, and P3.

Finally, we examined whether the topography of the N400 effect differs for the two word categories. For this end, the amplitudes of the difference potentials "unrelated–strongly related" were transformed to standardized z scores and submitted to an ANOVA with factors Electrode Clusters × Word Category. This analysis revealed no reliable topographic difference, not if computed with the 19 electrode clusters, $F(1,18) = 1.37$, $p = .1939$, $\epsilon = .59$ or with the full set of 124 electrodes, $F(1,123) = .96$, $p = .5359$, $\epsilon = .30$. That is, the amplitude difference of the N400 effect between verbs and nouns that is evident in Figure 4 has to be attributed to a different strength of one and the same generator. Because moderately related verbs elicited no reliable N400 effect at all, this topographic analysis was not repeated for the difference potentials "moderately related–strongly related."

Discussion

Priming effects

The behavioral data confirm the well-established finding of a semantic priming effect: Target words being primed by a preceding semantic associate are recognized as legal words faster and with higher accuracy than unprimed words. In most of the previous lexical decision studies, primes and targets had been selected from the categories of content words that spontaneously trigger paradigmatic associations (nouns and adjectives). Our study extends the textbook finding to the word category of verbs. The pattern of effects was the same for both types of words, that is, there was a gradual increase of response time and error rate with decreasing relatedness of prime and target. These effects proved to be independent of SOA for both word categories. The finding that there is a reliable priming effect between verb pairs confirms previous observations reported by Zwitserlood et al. (1996) and it suggests that a verb may not only trigger its syntagmatic associates but also other paradigmatically associated verbs.

The similarity of the two effect patterns suggests that the priming effect between semantically associated nouns and semantically associated verbs must have a similar functional cause in a primed LDT. Nevertheless, response times to verb targets were on the average 30 ms slower than to noun targets. This prolongation was a general effect, that is, it was significant for all three types of word targets—unrelated, moderately related, and strongly related targets. Therefore, the effect cannot be attributed to a different semantic relatedness within the two sets of word pairs. Rather, there seems to be some verb-specific process that, in general, prolongs the lexical decision time for a verb target following a verb prime.

The behavioral priming effects were mirrored by amplitude changes of the ERPs within the N400 latency window. ERPs evoked by the nouns nicely replicated previous findings that the amplitude of the N400 effect increases systematically with decreasing degrees of associative strength between a priming context and a target (e.g., with decreasing cloze probability of a word in a sentence (Kutas & Hillyard, 1984), with decreasing relatedness of an exemplar to an expected category (Federmeier & Kutas, 1999), or with decreasing numerical relatedness of a number in an arithmetic equation (Niedeggen & Rösler, 1999). Our data show that this gradual amplitude modulation is not only present in the context of a sentence, but can already be observed with the sparse semantic context established by a single word. Moreover, a reliable N400 effect was evoked by verb targets, too. Unrelated verb targets evoked a significantly larger negativity around 400 ms after target onset than strongly and moderately related verb targets. However, the net amplitude of the N400 effect (difference between unrelated and strongly related targets) was smaller for verbs than for nouns. This suggests that the semantic relatedness of strongly associated verb targets, in general, may have been less tight than that between strongly associated noun targets. In other words, it looks as if strongly related verb targets were primed only to such a degree as moderately related noun targets. (This conclusion does not necessarily contradict the behavioral data showing a comparable semantic similarity rating for both types of words [see Table 1]. Because the ratings provide data on an interval scale only, it is possible that the rating scale was used with a different calibration factor for nouns and verbs).

Generator Differences Between Nouns and Verbs?

The study revealed three ERP differences between the two word categories:

1. Noun primes evoked a more negative ERP than verb primes between 90 and 120 ms and 150 and 180 ms after word onset. This effect was present in the raw ERPs only, it disappeared after *z*-standardization. Thus, this effect indicates an amplitude modulation of one and the same generator for the two types of words.
2. Verb targets evoked a more negative ERP than noun targets within the time windows 30–90 ms, 330–420 ms, 480–630 ms, and 780–900 ms after target onset. After *z*-standardization, a significant interaction between electrode clusters and word category was still present for the time windows 210–240 ms and 360–600 ms. This indicates a genuine topographic difference between the two waveforms.
3. The N400 effect, that is, the difference between unrelated and strongly related targets, had a larger amplitude for nouns than for verbs. However, after *z*-standardization, any difference between the N400 effects of the two word categories disappeared.

Findings (1) and (3) clearly contradict the claim that verbs and nouns evoke electrophysiological responses in the EEG that are manifestations of different generators (Pulvermüller, 1999). At first glance, finding (2) seems to support this claim; however, one should be cautious with such a conclusion. As revealed by the behavioral data, verb and noun targets triggered the word category decision with a different latency: On average the response to verbs was 32 ms slower than to nouns. The average response times amounted to 666 ms for nouns and 698 ms for verbs. A difference between the two ERP waveforms could therefore be due to a different timing of the response preparation and execution processes. This possibility cannot be ruled out on the basis of the present set of data and it applies likewise to the data reported by Preissl, Pulvermüller, Lutzenberger, and Birbaumer (1995). In their study, a LDT was used, too, and it cannot be excluded that response times for verbs and nouns were different, too, (unfortunately, Preissl et al. did not report response times and error rates). Moreover, Preissl et al. had found (without standardization) a relatively less pronounced P200 component for nouns than for verbs, that is, nouns were more negative than verbs between 200–230 ms at C3, whereas we found (with standardization) that nouns were less negative than verbs at frontocentral electrodes between 210–240 ms, that is, the polarity of the effect is reversed. The data of Pulvermüller, Lutzenberger, and Preissl (1999) are difficult to relate to these results, because they did not report original waveforms but only the results of an unstandardized CSD analysis. This proved that verbs showed relatively more "ingoing currents" at C3/C4 and relatively more "outgoing currents" at O1/O2 between 200 and 230 ms. Due to the spherical spline interpolation, it is unclear how negativities and positivities of original potentials are mapped onto the currents of a CSD analysis.

To sum up: In both studies in which significant differences between ERPs evoked by nouns and verbs were reported so far (Preissl et al., 1995; Pulvermüller et al., 1999), the results were obtained from unnormalized ERP waveforms or CSD calculations. In our study, most of the topographic differences that we have observed in the raw data vanished after standardization. Therefore, it is questionable whether the positive results of the Pulvermüller group would survive a *z*-score normalization. At least the nil finding observed for the primes in our study nourishes a strong doubt that this would be the case. Moreover, the polarity of one result that survived standardization in our study is contrary to the positive result reported by Preissl et al.

Thus, the available evidence in favor of an electrophysiological distinction between nouns and verbs is not very convincing so far. At least a primed LDT as used in the present study and a similar priming situation as in the study of Gomes et al. (1997) do not disclose any reliable ERP difference between the two word categories that can be unequivocally attributed to the processing of the two word categories as such. This negative result is all the more surprising as we had expected a topographic difference for the N400 net effect. As outlined in the introduction, the N400 effect is calculated as the ERP difference between unrelated and strongly related items. Therefore, the effect is uncontaminated by any response-related differences, for example, different response latencies, and it should reflect the additional activation in the semantic network in pure form[2].

Of course, one could argue that N400 does not reflect automatic lexical access but rather more strategic, decision-related processes. However, decision processes that evaluate the semantic relatedness of the currently processed word with the previous context must activate memory representations that denote the semantic content of a word. Meaning is most likely defined by the associations that a word shares with other entries of the memory system (cf., e.g., the similarity-contrast model of Tversky, 1977). Given verbs and nouns and their denotative "networks" are stored at distinct locations at all, because they are either

[2]The negative finding is also at variance with some older work (Brown, Marsh, & Smith, 1976) in which ERP differences were reported for one and the same ambiguous word if it was understood either as a verb or as a noun in a short phrase as /it was led/. However, this result is difficult to relate to the present work. First, one and the same word /led/ was repeated 60 times in different blocks with the advance instruction that the word should be interpreted in the phrase either as a verb or as a noun. It is questionable whether such a frequent repetition of a word will capture processes related to an activation of semantic representations at all. Frequent repetitions induce semantic saturation and it is likely that in these studies not differences in meaning but differences in the syntactic status of the word were studied. Moreover, Brown et al. used only four electrodes, which can hardly capture subtle topographic differences.

more closely linked to action associations or to visual-object associations, then the two word categories should activate distinct memory partitions in any case, whether it is automatic lexical access or conscious evaluation.

So, if the N400 effect is a sign of semantic activation and if the networks for verbs and nouns are topographically distinct, then the topography of the N400 effect evoked by verbs and nouns should have been different. As this is not the case, we have to look for the flaw in the chain of our arguments. There are three possibilities.

First, the assumption that the N400 effect is a manifestation of additional activation processes within the semantic network could be false. However, there are many results that support this very interpretation of the N400, in particular priming effects with short SOAs and masked primes (Kiefer & Spitzer, 2000; Rolke et al., 2001) and graded amplitude changes of the N400 depending on the amount of priming (Federmeier & Kutas, 1999; Kutas & Van Petten, 1988; Niedeggen & Rösler, 1999; Niedeggen et al., 1999; Van Petten & Kutas, 1990). Moreover, the hypothesis nicely integrates, by and large, the whole N400 literature. Therefore, it would be premature to discard such a powerful hypothesis.

Second, mental representations of verbs and nouns may not be bound to topographically distinct generators, because the elements of the two word categories are represented in one lexicon whose biological basis is one large neuronal network. Although possible, this suggestion is at variance with the lesion findings (Caramazza & Hillis, 1991; Chen & Bates, 1998; Damasio & Tranel, 1993), at least as long as one takes these findings as evidence that verbs and nouns are linked to distinct storage/processing systems. Connectionist models provided some evidence that such a conclusion has not necessarily been drawn from lesion results. A "lesion" within a neural network model of word representations can produce category-specific deficits within a lexicon, although the words are represented with differing numbers and strengths of connections all over the network (Farah & McClelland, 1991; Hinton & Shallice, 1991). But even if this holds true for the network models, it is nevertheless striking that the lesion effects found in patients are anatomically consistent in that verb access is more likely disturbed with anterior and noun access with posterior lesion sites. This suggests an anatomical difference in the "centers of gravity" for verb and noun nodes. Therefore, we are hesitant to accept the hypothesis that only one undifferentiated neuronal network exists for lexical/semantic representations.

Finally, it could be that both verbs and nouns exert their priming effect on the following target by noun associations only. As outlined in the introduction, verbs usually trigger syntagmatic associations in an association test and these are direct and indirect objects or agents (sentence subjects), for example, the German verb *kochen* (to cook) might trigger *Essen* (dinner), *Fleisch* (meat), *Mutter* (mother), or *Köchin* (female cook), and a following related verb *brutzeln* (to sizzle) then might trigger other related nouns like *Braten* (roast beef), *Herd* (oven), and again *Mutter* or *Köchin*. If so, the main spread of activation would take place within the noun partition of the lexicon with both types of prime–target combinations and then it would be unreasonable to expect a topographic difference between the two priming conditions at all.

For the time being, we think the last explanation to be the most plausible and we are currently running an experiment to test it (Scherag, Rösler, Streb, & Khader, 2001). The idea is to circumvent such an intermediate activation of nouns after a verb prime. This should be possible if a priming context is constructed that defines not only a semantic expectation but that also restricts the syntactic category of the next word. By means of this, a more selective activation of the verb and the noun partition of the lexicon should be created and possible topographic differences between verb and noun processing should become manifest.

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