

EEG brain mapping of phonological and semantic tasks in Italian and German languages

Alessandro Angrilli^{a,b,*}, Christian Dobel^a, Brigitte Rockstroh^a,
Luciano Stegagno^b, Thomas Elbert^a

^a*Fachgruppe Psychologie, University of Konstanz, Fach D25, D-78457, Konstanz, Germany*

^b*Department of General Psychology, University of Padova, Padova, Italy*

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Abstract

Objectives: Event-related potential correlates of phonological encoding – as compared with lexical access and semantic categorization – were measured in two studies involving two groups of 14 German and 14 Italian subjects.

Methods: A two stimulus reaction time paradigm was used. Stimulus pairs presented one-by-one with 2 s inter-stimulus intervals (ISI) had to be matched with respect to lexical identity (word-picture) in a word comprehension task or with respect to the phonological representative of objects in a rhyming task. A semantic categorization task was added for the Italian sample. In both studies, the EEG was recorded from 26 scalp electrodes according to the 10–20 system. The slow negative potential during the ISI (CNV) was determined as the electrocortical correlate of preparation for and activation of the specific language-related task.

Results: In both samples, phonological encoding (rhyming) evoked a more pronounced CNV over the left- compared with the right-frontal area, while less lateralized central dominance of the CNV was found in the word comprehension task. Semantic categorization was accompanied by the least asymmetry of activity.

Conclusions: Results indicate that the different degree of asymmetry induced by phonological and semantic processing may be determined from the scalp distribution of slow cortical potentials with cross-lingual reliability. © 2000 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Slow cortical potentials; Phonological encoding; Semantic processing; Lexical access; Language

1. Introduction

According to a model proposed by Baddeley (1992), phonological processes engage verbal short-term memory (vSTM) which comprises two subcomponents, phonological short-term store, and articulatory loop. While the phonological short-term store keeps acoustic or speech-based information active for 1 or 2 s, the articulatory loop consists of a subvocal rehearsal which prevents the decay of the mnemonic trace during longer intervals.

Attempts to localize phonological processing in the brain are based on neuropsychological evidence obtained from aphasic patients as well as on imaging studies in healthy subjects. For instance, verbal short-term memory is impaired in aphasic patients (Zangwill, 1946; Warrington and Rabin, 1971; De Renzi and Nichelli, 1975). The sites of

lesions inducing vSTM impairment typically involve the left posterior cortices (parietal and/or temporoparietal cortices). It has also been reported that articulation processes are impaired in patients with lesions in Broca's area (Mazzocchi and Vignolo, 1979). A phonetic discrimination deficit is found in patients with lesions of the left frontal cortex (Taylor, 1979). In general, phonemic speech errors are characteristic of lesions in the perisylvian area, whereas lexical errors characterize other more distributed areas (Cappa et al., 1981).

Brain imaging studies employ different methods to induce phonological processes and verbal working memory activity such as acoustic analysis of phonemic sequences (Démonet et al., 1992, 1994), syllable rhyming (Zatorre et al., 1992), rhyming of letter sounds (Sergent et al., 1992; Sergent, 1994) or consonant rhyming (Paulesu et al., 1993). Results provide converging evidence that the left frontal cortex, including Brodmann areas 44 (Broca's area) and 45, is activated during the subvocal rehearsal required in rhyming tasks, while activity of the premotor cortex (area

* Corresponding author. Present address: Department of General Psychology, Via Venezia 8, 35131 Padova, Italy. Tel.: +39-049-8276692; fax: +39-049-8276600.

E-mail address: angrilli@psico.unipd.it (A. Angrilli)

6) and the left temporoparietal cortex (areas 21, 22 and 40) is less consistently found.

The few data available in the EEG literature are consistent with PET research. In two event-related potential experiments aimed at studying vSTM, the tasks consisted of two stimulus delayed phonological matching, and used a combination of consonants or syllables to form the non-word stimuli (Ruchkin et al., 1990, 1997). Results revealed a slow negative wave peaking over the left frontal areas.

Studies focusing on lexical-semantic processing have yielded more variable results, which may be attributed to different designs, stimuli and methods. Nevertheless, there seems to be agreement that semantic processing is less localized, since it involves the activation of distributed networks in the brain (Cappa et al., 1981; Wise et al., 1991; Braitenberg and Pulvermüller, 1992; Démonet et al., 1992; Perani et al., 1993; Damasio et al., 1996; Pulvermüller, 1996; Vanderberghe et al., 1996). Within this general framework, the methods used to measure brain activity account for most differences in lateralization of semantic tasks. Some brain imaging investigations also show left lateralization in semantic tasks (Wise et al., 1991; Démonet et al., 1992; Damasio et al., 1996; Vanderberghe et al., 1996), whereas most ERP research points to consistent bilateral activation during semantic categorization. Electrical brain activity, as measured by means of evoked potentials, may be more sensitive to transient activation of areas which do not show a bulky metabolism increase (as measured by PET or fMRI)¹. Kutas and Hillyard (1982) reported that a bilateral (slightly larger on the right hemisphere) negative wave (N400) was evoked by semantic incongruence of a word terminating a syntactically correct phrase. More recently, similar bilateral N400 activation has been observed during a semantic task, also in potentials evoked by Italian words in native Italian speakers (Cobianchi and Giaquinto, 1997). Using a dense electrode array, Abdullaev and Posner (1997) found bilateral temporal activation during a difficult semantic task, as well as activity over the right Wernicke's field at 650 ms from word onset. Similar symmetry of activation induced by a semantic task and extended throughout the 1 s of word presentation was found by Skrandies (1998). However, the question whether observed brain activity is really specific to word or language processing has been raised in a number of studies. For instance, Rockstroh et al. (1979) and Elbert (1992) observed a post-imperative

negative wave in ambiguous or uncontrollable conditions, suggesting that the N400 may be a member of a family of negative waves which appear when the subject re-evaluates contingencies (Rockstroh et al., 1989).

Pulvermüller and co-worker (Braitenberg and Pulvermüller, 1992; Pulvermüller, 1996) base their theory of language on the Hebbian principle of associative learning. Words are represented by distributed cell assemblies which form during learning, including those neurons which then show correlated firing. A word, for instance, perceived visually and referring to objects, is represented by a cell assembly with members even beyond the perisylvian region, i.e. in visual areas including the occipital lobes and the inferior temporal region.

Taken together, evidence indicates that phonological processes are related to the left opercular area, while distributed cortical activation arises during lexical-semantic tasks. The present study aimed at adding further evidence by examining the scalp distribution of evoked potentials during a rhyming as compared to a word comprehension task. For this purpose, tasks were embedded in a two stimulus (or delayed matching) design, in which a first stimulus (S1) was followed after a constant inter-stimulus interval by a second stimulus (S2) to which a match-mismatch decision was to be made.

The slow negative potential which develops in the inter-stimulus interval (contingent negative variation, CNV) is considered to represent activation of those brain areas involved in the task performance signalled by S1. The scalp distribution of this CNV and location of its relative maximum may point to the spatial location of the process under study. In line with previous evidence, we expected the rhyming task to induce activation focussed over the left hemisphere, in particular over the left frontal cortex, while lexical (word comprehension) and semantic tasks were expected to induce less lateralized CNV distribution. Lastly, by comparing similar tasks and identical ERP recording protocols in two samples of German and Italian subjects, i.e. using words from different languages, the present study served to examine the general validity of hypotheses on lateralization of language-related processing.

2. Materials and methods

2.1. Subjects

Fourteen native Italian subjects (9 males, 5 females; mean age 29.3 ± 2.2 years, range 26–33 years) and 14 native German subjects (10 males, 4 females; mean age 39.6 ± 8.1 years, range 23–50 years) gave their written consent to participate in the experiment. All subjects were 100% right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1977). None of the subjects had been treated for any neurological or psychiatric disorder and were not under current medication. German and Italian groups were studied

¹ In other terms, the typical transient electrical changes induced in studies based on evoked potentials are interspersed with long intervals. Therefore, although areas are well (electrically) activated during stimulation, brain metabolism is not expected to change significantly, as this would represent the integral of the activity measured over the whole trial (or several trials), including both the short stimulation and the relatively long inter-stimulus interval. For this reason, electrical measures may be more sensitive in detecting activation, whereas a metabolism change might be so small that it is not measurable. It is conceivable that, during language tasks, whatever the task, the left hemisphere increases metabolism. However, the areas (seemingly) metabolically silent may still be electrically active.

in Konstanz and Padova, respectively. However, the equipment, procedures, setting and analyses (but not all the stimulus material) were exactly the same for the two studies.

2.2. Apparatus and physiological recordings

Electroencephalograms were measured by means of 26 Sn electrodes (mounted on an ElectroCap) attached according to the International 10–20 system (Jasper, 1958) using a DC-MES 32 channel amplifier (MES, München). Twenty-one electrodes were placed at standard positions (including mastoids). Five additional electrodes were placed below each eye, on the two external canthii and on the nasion. Cz was used as a reference. The amplitude resolution was 0.1 μ V. The bandwidth ranged from DC to 30 Hz (6 dB/octave). The sampling rate was set at 100 Hz.

2.3. Stimuli, tasks and procedure

Words and pictures of objects served as visual stimuli. Line drawings of objects representing concrete and frequent words in the respective languages (Italian and German) were selected from the collection of Snodgrass and Vanderwart (1980). The Italian words were selected from a dictionary of 5000 Italian written words (Bortolini et al., 1972). The German words were selected according to Hager and Hasselhorn (1994). Bi- and tri-syllabic concrete words with average frequency were selected.

In the phonological encoding task of the German experiment, two pictures of objects were presented one after the other, separated by an ISI of 2 s. The subject's task was to decide by pressing a button with the left index or left middle finger, whether the words represented by the picture would rhyme (e.g. cat–hat) or not (e.g. cat–hut). Fifty-four trials were included in this task. In the Italian study, the rhyming task was comprised two words presented one after the other. Following the onset of the second word (S2), the subject had to decide whether the words were phonologically similar (rhyming) or not. Additionally, the Italian sample performed a semantic categorization task, in which the same words used in the rhyming task were presented as S1. The subject had to decide whether the second word (S2) was (semantically) related to the first. Both tasks were presented for 80 trials each.

In the word comprehension task, a word was presented as S1 for 1 s followed after a 2 s ISI by the presentation of a picture of an object (see Fig. 1a for trial structure). The subject's task was to decide by pressing a button whether the picture presented as S2 matched the word (the object represented by the word) in S1 or not. S2 remained on the screen until one of two keys was pressed. Eighty-two trials were included in this task.

In all tasks, 50% matches were randomly interspersed with 50% mismatch trials. In both samples the order of the tasks was randomly assigned across subjects.

Since Italian is a highly transparent language (that is, phonology matches orthography), and therefore rhyme

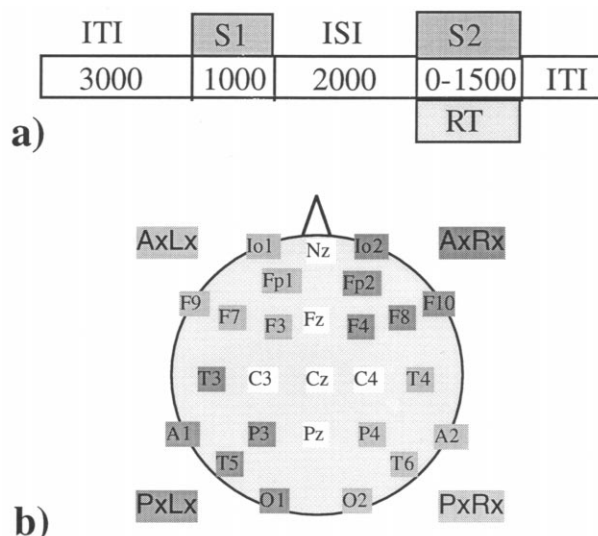


Fig. 1. (a) Organization of experimental trial. Durations indicated in milliseconds. ITI, inter-trial interval; ISI, inter-stimulus interval. (b) Clustering of electrodes in 4 quadrants: anterior left (AxLx), anterior right (AxRx), posterior left (PxLx), posterior right (PxRx).

matching may be performed with few errors also by reading the end letters of the written words, we tested the subjects' strategy during the explanation session preceding the experiment. In this session we included a few pairs of words which are recognized as rhyming only when an orthographic strategy is chosen, but that do not rhyme at all (for instance the pairs *penna*–*schiena*, *quaderno*–*pugno*, etc.). A few of these pairs were also included in the experimental material to check shift strategies during the rhyming task.

2.4. Data analysis

Raw data were continuously recorded in DC mode by fulfilling the main requirements for high quality DC recordings (Bauer et al., 1989). Every task lasted for approximately 10 min. Thus, as is typical in DC recordings, traces also included the very slow and random DC drift of amplifiers. The slow DC shifts were removed and corrected by fourth order polynomial detrending using means in relation to markers over the entire recording epoch. Data were then transformed into 15 s epochs including 1 s before and 14 s following S1. Since the CNV under study develops within a 2 s interval, linear detrending performed in the 15 s epochs aims at further eliminating any CNV-unrelated shift. The CNV interval, in fact, only represents a small fraction of the detrended epoch and is not affected by 15 s linear detrending. Therefore, from each epoch and each channel a linear trend was subtracted to eliminate further slow DC shifts. A 100 ms baseline preceding S1 was subtracted from the whole trial epoch. After conversion to average reference (resulting in 25 + 1 channels), the single trials were corrected for eye movement artefacts (vertical and horizontal movements and blinking) according to Berg

and Scherg (1991, 1994). The single trials were then visually inspected for remaining artefacts and rejected if necessary. After correction, all accepted trials were averaged for each task and for each subject. The CNV was determined as the mean potential shift (relative to baseline) during the 2 s interval prior to the onset of S2². Maps were obtained through spline interpolation methods (Perrin et al., 1989).

For each sample, task-specific lateralization of the CNV was evaluated by means of analyses of variance (ANOVA) comparing the average amplitude between the two tasks (3 in the Italian sample) and 4 groups of electrodes. This choice was made in preference to other alternatives as a consequence of the need to simplify and make statistical analysis more robust. First, the reduction of statistics to 4 levels in place of the possible 26 (one for each channel) increases the power of the statistics themselves (Stevens, 1990) and simplifies the interpretation of results. Second, the division of the scalp into 4 quadrants allows the use of two factors with two levels each: antero-posterior asymmetry and laterality, and, more interestingly, their interaction. Third, the need to keep the signal-to-noise ratio balanced for each electrode group forced us to average the same number of electrodes in each quadrant. After these considerations, midline electrodes, plus C3 and C4 had to be discarded from statistical computation, and each quadrant was comprised of 5 electrodes: anterior left (AxLx: Io1, Fp1, F3, F7, F9), anterior right (AxRx: Io2, Fp2, F4, F8, F10), posterior left (PxLx: T3, P3, A2, T5, O1) and posterior right (PxRx: T4, P4, A1, T4, O2). The average electrical activity of all electrodes was computed in every quadrant (Fig. 1b). Two factors were introduced in the ANOVAs: laterality (left versus right hemisphere) and antero-posterior asymmetry (anterior versus posterior sites).

Performance was examined by comparing the error rates and mean reaction time between tasks. A further statistical comparison was computed between German and Italian

samples (between-group factor) in the comparable tasks: word comprehension and rhyming. Newman-Keuls tests were computed for all post-hoc comparisons.

3. Results

Overall, 83 and 62% of trials were averaged in the German and Italian samples, respectively.

In a first step, qualitative information about electrical activity measured on the scalp was obtained from spline maps of the scalp potentials (Fig. 2). Grand-average ERP waveforms during word comprehension, rhyming and semantic tasks are also shown in Figs. 3 and 4.

Fig. 2 illustrates grand averages of these maps during the 2 s ISI calculated separately for the two samples. The German group displayed the peak of negativity over central areas during the word comprehension task (Fig. 2B), while during rhyming the negative shift was greatest over the left frontal cortex (Fig. 2A). The Italian group displayed comparable central negativity during the word comprehension task (Fig. 2E). This peak, however, was shifted towards the left side (C3) leaving maximum positivity over the right prefrontal region. Rhyming (Fig. 2C) was accompanied by left central-posterior negativity and right prefrontal positivity. Only the semantic task (Fig. 2D) induced a negative peak in the right hemisphere over parietal areas. In all tasks, the Italian sample exhibited positivity over right prefrontal regions.

In the German sample (Fig. 3), the generally more pronounced CNV during rhyming compared to word comprehension was confirmed by a main effect of the task ($F_{1,13} = 6.92$, $P < 0.01$); the task-specific scalp distribution with more pronounced left-frontal (F9, F7, F3) negativity and more right-frontal (Io2, Fp2, F10, F8, F4, C4, T4) positivity during rhyming and reversed asymmetry during word comprehension was indicated by the task–laterality interaction ($F_{1,13} = 5.94$, $P < 0.05$; Fig. 5a). Asymmetry was larger over frontal (post-hoc $P < 0.01$) than posterior sites during rhyming compared with word comprehension, as indicated by the task–laterality–antero-posterior interaction ($F_{1,13} = 5.78$, $P < 0.05$; Fig. 5b). Furthermore, during rhyming, the left posterior region was more negative than word comprehension at both posterior sites and the left anterior site ($P < 0.05$).

In the Italian group, a main effect in antero-posterior asymmetry ($F_{1,13} = 4.44$, $P < 0.05$) was found: higher positivity was present at frontal compared with posterior sites. A laterality main effect was also evident, with larger negativity in the left than in the right hemisphere ($F_{1,13} = 4.55$, $P < 0.05$). The significant interaction observed between laterality and antero-posterior asymmetry ($F_{1,13} = 9.67$, $P < 0.01$) indicates that, overall, tasks induced right–left hemisphere asymmetry (larger negativity in the left than in the right frontal areas) only at the frontal sites ($P < 0.01$) (Fig. 5d).

² It is worth pointing out that in the present experiment we analyzed electrical brain activity in the interval between the stimuli, rather than the stimuli themselves or the behavioural responses. Although processes and scalp activity measured during stimulation (that is during either S1 or S2) are supposed to differ from the above mentioned CNV (which is produced during the ISI, that is under no stimulation condition), we hypothesized the tasks to influence brain activity starting at late components of S1, then in the ISI during which the CNV was recorded, and at the end, during the comparison of S2 with the encoded S1. Thus, we expected, after S1 offset during the ISI, a sustained task-dependent cortical activation induced by S1 in preparation (and prevision) of the comparison with S2. Since S2-evoked responses are affected by both motor activity and eye (and body) artefacts, the analysis of the potentials evoked by S2 is, at least in part (late components), problematic. During S1, subjects are in a perceptual setting and therefore are mostly engaged in the stimulus recognition and classification. Therefore, the CNV is being recorded in that interval during which subjects are not engaged in attentional processes and evoked potentials are not affected by strong motor and eye artefacts. Within this framework, any statistics showing CNV differences among the tasks would represent a demonstration in favour of our hypothesis that a task-related preparation is being performed during the CNV interval.

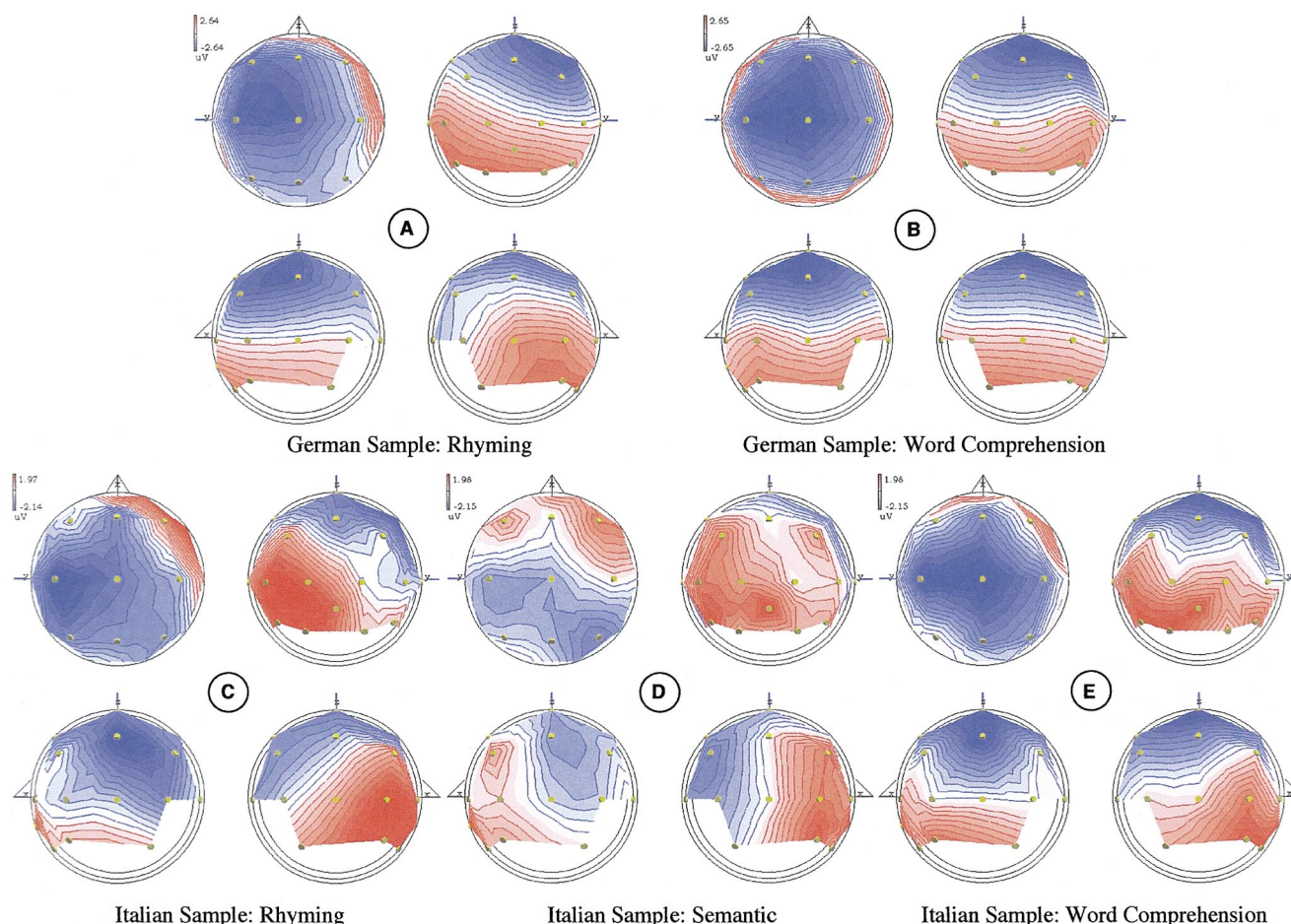


Fig. 2. Spline maps of German and Italian samples. Each cluster of 4 maps represents respectively: upper left, top view of scalp; upper right, frontal view; lower left, left lateral view; lower right, right lateral view. Maps of German sample on rhyme (A) and word comprehension tasks (B). Maps of Italian sample on rhyme (C), semantic (D) and word comprehension tasks (E). Blue, negativity; red, positivity. Maps represent mean 2 s interval recorded between S1 and S2.

The task–laterality interaction was significant ($F_{2,26} = 6.02$, $P < 0.01$). The grand-average waveforms (Fig. 4) revealed larger negativity over the left hemisphere (F7, F3, C3, P3, T5) during rhyming compared with the semantic task, while pronounced positivity predominated at the right prefrontal electrodes (Io2, Fz, Fp2, F4, F8, F10). Post-hoc tests showed greater left negativity and higher right positivity during the rhyming ($P < 0.01$) than during the semantic and word comprehension tasks ($P > 0.30$; Fig. 5c). Furthermore, in the right frontal area there was significantly higher positivity during the rhyming than during the semantic task ($P < 0.05$).

3.1. Asymmetry

ERP lateralization during the rhyming task was examined by averaging across the 11 electrodes located over one hemisphere and subtracting the left from the right hemisphere average (a positive value indicates left hemisphere dominance). This asymmetry score indicates that 64% of Italians and 78% of Germans produced left hemisphere dominance during the rhyming task. When considering elec-

trodes only over the anterior quadrants, 85% of Italians and 78% of Germans showed left hemisphere dominance.

3.2. Performance

In the German sample (Fig. 6a), the decision as to whether picture-related words rhymed or not took significantly longer than word comprehension, as confirmed by a significant task effect for response latency ($F_{2,26} = 35.32$, $P < 0.01$). Furthermore, subjects made more errors during rhyming compared with word comprehension ($F_{1,13} = 29.93$, $P < 0.01$; Fig. 6b). Interestingly, in the Italian sample (Fig. 6c), response latencies were longest in the semantic task compared with both word comprehension and rhyming ($F_{2,26} = 25.13$, $P < 0.01$; post-hoc comparisons $P < 0.01$). No difference was found between these two tasks. Error rates reflected these differences only qualitatively (higher rates for the semantic task), without reaching significance ($F_{2,26} = 2.40$, NS; Fig. 6d).

3.3. Comparison between groups

In order to explore the validity of ERP patterns across

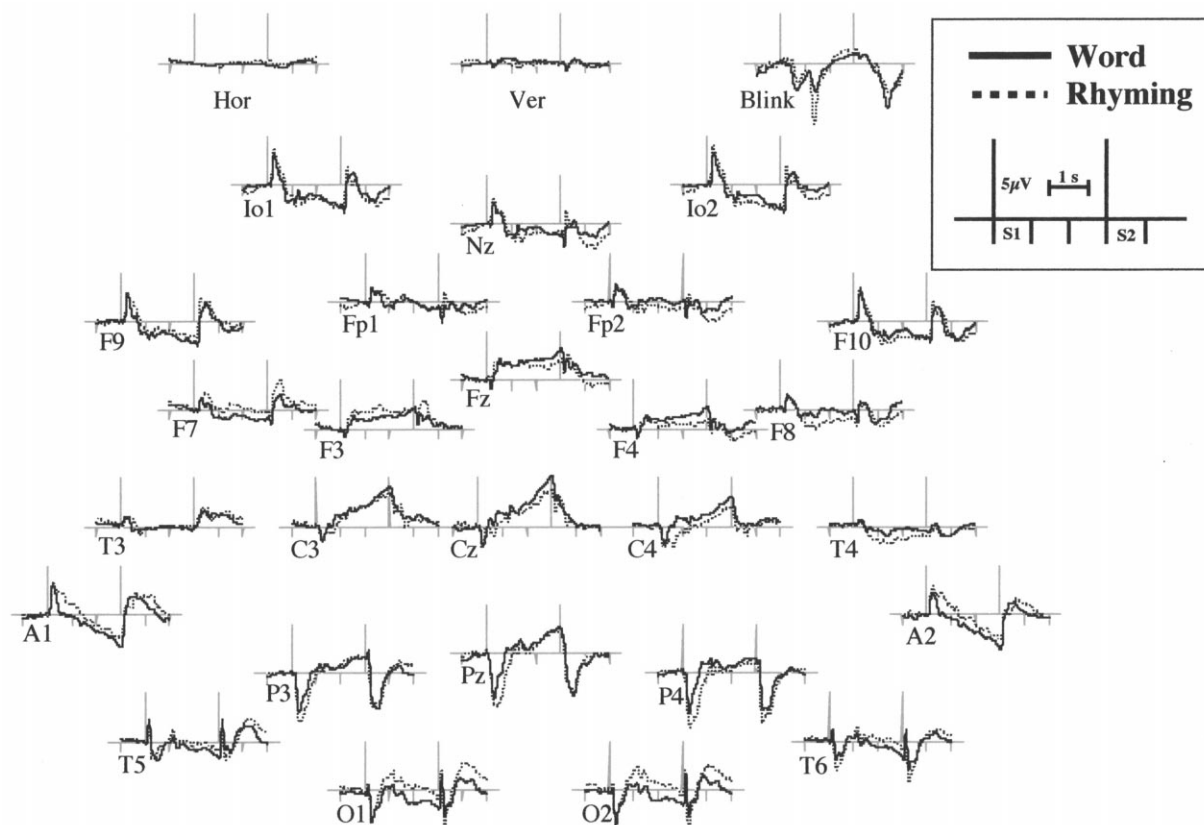


Fig. 3. Grand-averaged waveforms obtained from German sample: comparison between word comprehension (full line) and rhyme (dashed line) tasks across 26 channels. Top 3 waveforms from left to right represent horizontal eye movements, vertical eye movements and blinks, respectively. Eye-movement waveforms show the magnitude of eye artefacts prior to the correction procedure. Negativity is upward. Inset: amplitude, time scale and stimuli positions.

languages, an additional ANOVA, including the between-subjects factor group, compared the responses in the comparable tasks – rhyming and word comprehension – between the Italian and German samples.

Again, for both samples, more pronounced left than right hemisphere negativity (laterality: $F_{1,26} = 8.69$, $P < 0.01$), primarily over the anterior areas (laterality–antero-posterior: $F_{1,26} = 8.65$, $P < 0.01$), was confirmed (see Fig. 5b,d). Both samples displayed overall lower positivity during rhyming ($0.286 \mu\text{V}$) compared with word comprehension ($0.401 \mu\text{V}$) (task: $F_{1,26} = 6.83$, $P < 0.01$). The antero-posterior asymmetry showed only a tendency to significance ($F_{1,26} = 3.79$, $P < 0.06$): most variance in this factor is associated with the anterior-posterior difference (large right frontal positivity) found in the right hemisphere of the Italian sample ($P < 0.0001$). The significant laterality–task interaction ($F_{1,26} = 14.42$, $P < 0.01$) showed no difference between right and left hemisphere potentials during word comprehension, and about $1 \mu\text{V}$ difference during the rhyming task ($P < 0.01$).

The only group difference (group–laterality–antero-posterior asymmetry: $F_{1,26} = 4.07$, $P < 0.05$; Fig. 5b,d) indicated more pronounced right anterior positivity in Italian than German subjects ($P < 0.01$). The lack of interactions involving the variables group and task suggests

remarkable similarity of ERP patterns in samples of different native languages.

While ERP patterns did not markedly vary between samples, German subjects (Fig. 6a) responded more slowly than Italians ($F_{1,26} = 12.53$, $P < 0.01$; Fig. 6c), primarily in the rhyming task (group–task interaction: $F_{1,26} = 26.85$, $P < 0.01$) as compared with word comprehension ($P < 0.01$) and with Italian responses in both tasks ($P < 0.01$). There was no significant difference between groups in the word comprehension task ($P = 0.15$).

In error rate analysis (Fig. 6b,d), a significant interaction between task and group ($F_{1,26} = 24.44$, $P < 0.01$) indicates that only Germans produced more errors in rhyming judgement than in word comprehension ($P < 0.01$).

4. Discussion

Two results of the present studies are of particular interest: (1) the ERP asymmetry which appeared in the two different versions of a rhyming task but not in word comprehension or semantic categorization; and (2) the similarity of patterns across the two different languages. ERP asymmetry in the rhyming tasks suggests that the required process of phonological encoding does involve mainly the left hemi-

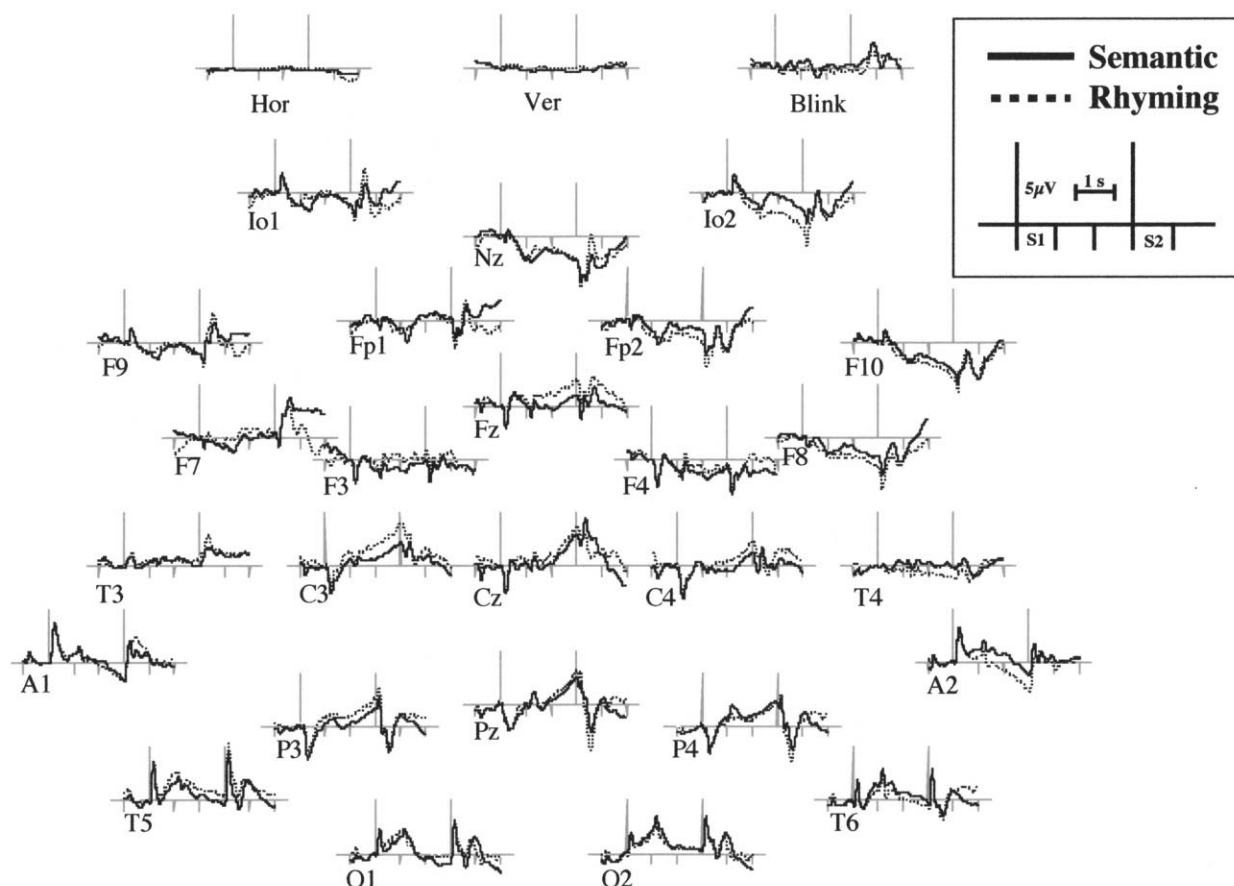


Fig. 4. Grand-averages obtained from Italian sample: comparison between semantic (full line) and rhyme (dashed line) tasks (for description, see legend of Fig. 3).

spheric and anterior areas, a result which was predicted on the basis of previous studies. Results are even more striking in view of the differences between the two studies: different languages and phonological rules, and pictures of objects in the German study and visually presented words (for rhyming) in the Italian study. While the differences found between the two samples may well be related to the listed experimental differences and require cautious discussion, the consistency of the effects in both rhyming and word comprehension points to the external validity of the results in relation to the main hypotheses.

Performance indicated that in Italian subjects the semantic task was more difficult than word comprehension and rhyming. For a number of reasons listed here, it is unlikely that such differences were due to a strategy of orthographic matching of the stimuli pairs which would have made the rhyming task easier. First, we were careful (see Section 2) not to allow subjects to use orthographic matching strategies. Second, the consistent topographical pattern observed during rhyming suggests similar (phonological) processes in the two samples. Furthermore, during semantic processing, several matching possibilities must be considered and a delay may therefore be expected in comparison with rhyming. The lack of differences in behavioural measures

between word comprehension and rhyming suggests that these two tasks were of similar difficulty. The longer motor response latencies and higher error rates observed in the German sample during rhyming probably result from the picture-to-word encoding needed for both S1 and S2 in the German but not the Italian version of the task. We have confirmation of this interpretation from another study of our group (unpublished data) using written material in both samples, in which we found longer reaction times during the semantic task and no differences between the groups in the rhyming task.

The Italian group showed peak activity which was slightly more posterior (Fig. 2C) than in the German sample. Although this effect was not significant, it may be related to the different stimuli used in the two samples: pictures for Germans and words for Italians. This interpretation is supported by the study of Vanderberghe et al. (1996) in which word encoding was associated with left superior temporal sulcus activation with respect to picture processing. Despite the differences, both samples produced the expected larger left frontal activation during rhyming. Thus, there may be justification for generalizing the result, suggesting that rhyming is an interesting tool to test left hemisphere dominance for language processing. The larger

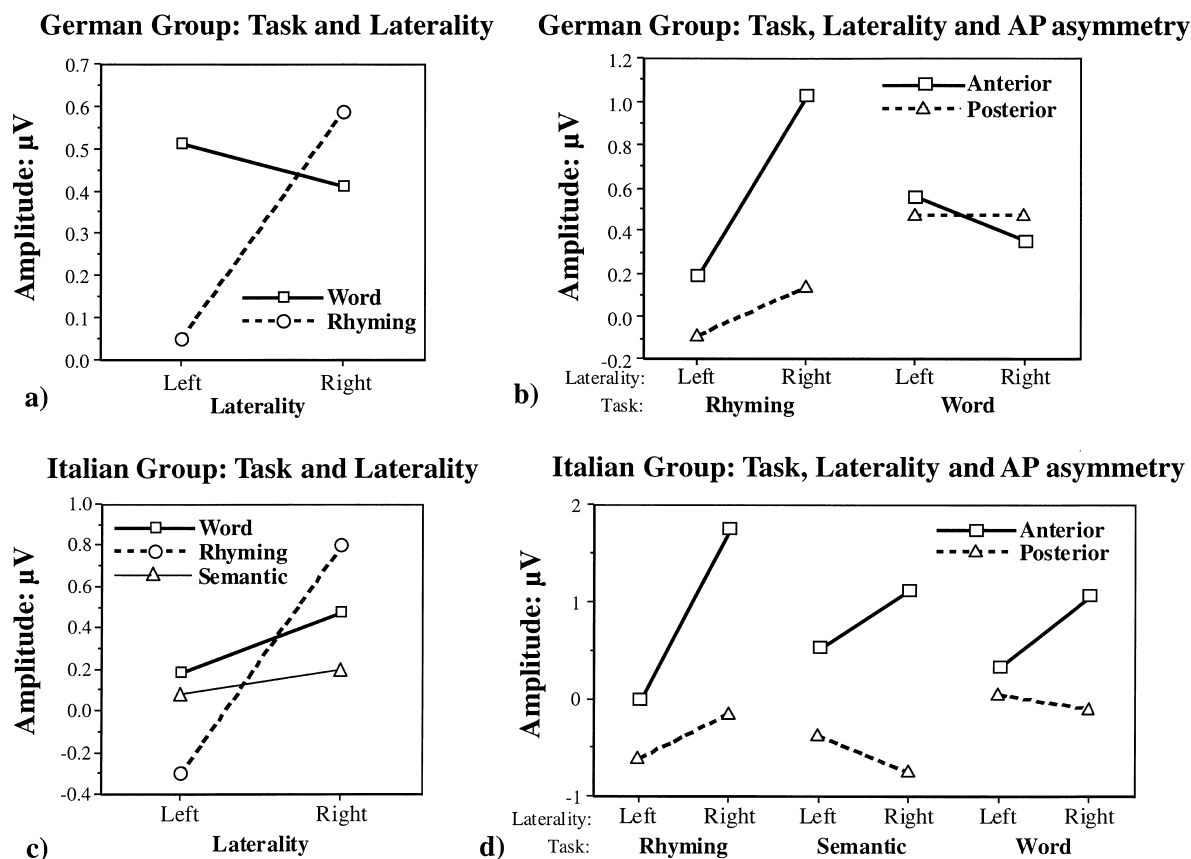


Fig. 5. Electrocortical responses (CNV amplitude) of German (a,b) and Italian (c,d) samples. (a,c) Task–laterality interaction; (b,d) task–laterality–antero-posterior interaction asymmetry interaction.

negativity found on the left frontal cortex is consistent with data from the literature showing activation of the left Broca's area, supplementary motor and premotor areas during phonological processing (Petersen et al., 1988) and in particular during a rhyming task which engages subvocal rehearsal (Ruchkin et al., 1990, 1997; Paulesu et al., 1993). The percentage of subjects showing left hemisphere lateralization during the rhyming task was 64% of Italians (85% if only the anterior quadrants were considered for the lateralization score) and 78% of Germans (78% with lateralization computed on anterior quadrants). These percentages are consistent with studies on dichotic listening (Kimura, 1967) and anatomical asymmetry of the planum temporale (Geschwind and Levitsky, 1968; Galaburda et al., 1978). These results suggest that the rhyming task is a valid measure of language lateralization in the cortex. It has been argued that brain imaging studies, including the present results, underestimate language lateralization when compared with results from the Wada test (Rasmussen and Milner, 1977). Instead, the Wada test may not do justice to the complexity of the lateralization of language processes of the intact brain (Kolb and Wishaw, 1996). It should be complemented or even replaced by brain imaging investigation in the future. According to the present results, the set of tasks applied should include rhyming.

The word comprehension task also produced comparable results in Italians and Germans, despite the possibility that the two groups may have used somewhat different strategies; longer (but not significant) reaction times of Germans in the word comprehension were compensated by smaller error rates (Fig. 6b) as compared with those made by Italians (Fig. 6d).

As already described in Section 1, scalp negativity, like that measured in a CNV paradigm, has been interpreted as an index of facilitation and activation of cortical areas involved in the specific task (Elbert and Rockstroh, 1987; Rockstroh et al., 1989). In all tasks, there was early activation (negativity), which reached a peak soon after S1 offset, over the primary visual cortex in the occipital areas (electrodes O1, O2). This effect is a probable consequence of the visual stimuli (pictures or written words) and is consistent with neuroimaging studies, showing that complex visual stimulation (word presentation) induces activation of the primary and associated visual cortices (Petersen et al., 1988, 1990). A similar time-dependent pattern was found in the temporal cortex in the region of the mastoids (A1 and A2). It is possible that early activation in the inferior temporal areas is due to stimulus-recognition processes mediated by an occipital-temporal-limbic circuit (Tranel and Damasio, 1985).

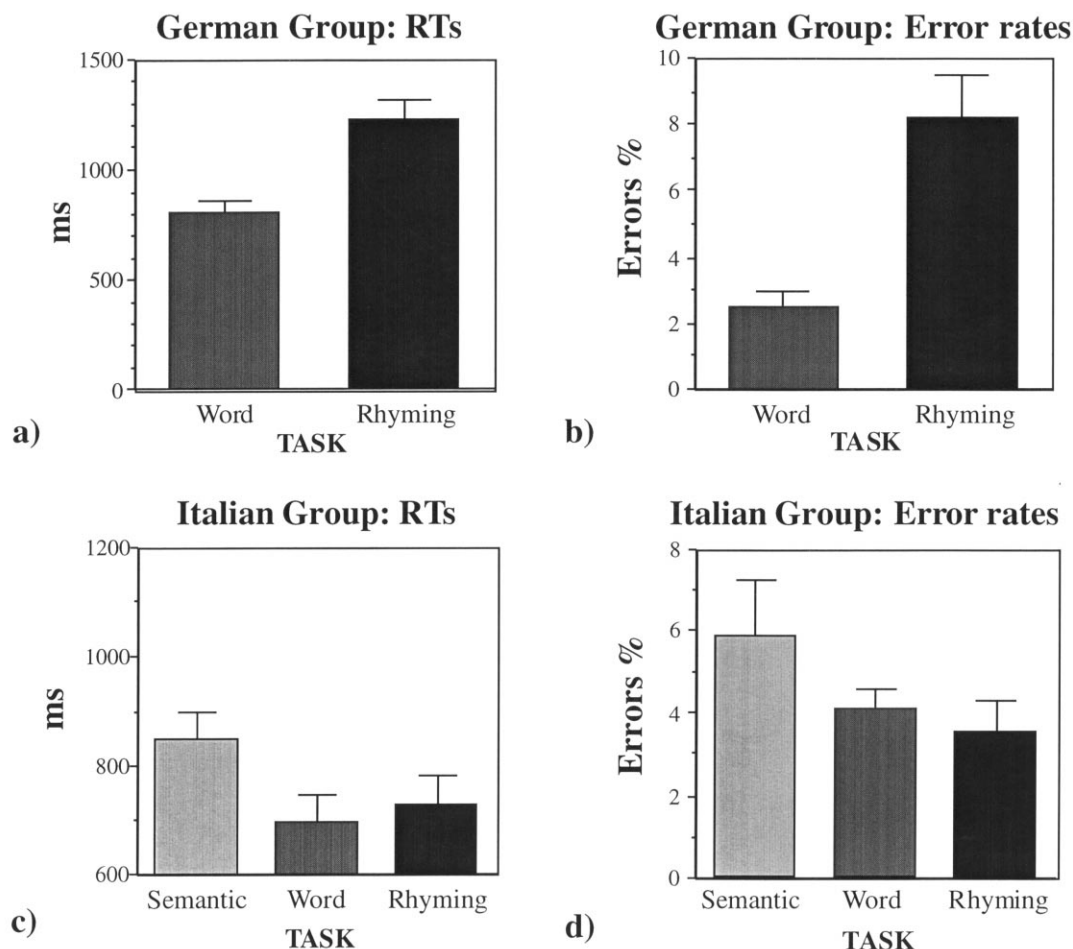


Fig. 6. Behavioural responses to S2 of German (a,b) and Italian (c,d) samples. (a,c) Reaction times (and SE bars); (b,d) error rates (and SE bars).

The described larger occipito-temporo-parietal activation indicates that during interval S1–S2, subjects were set to expect visual stimuli. Occipital activation decreased in the 2 s interval, while central negativity continuously increased (Figs. 3 and 4) until the onset of S2 (electrodes Cz, C3, C4, Pz). In CNV paradigms, the electrical negativity of the scalp typically is focussed in the frontal cortex (Birbaumer et al., 1990), including supplementary motor and premotor areas which are activated in preparation for an imperative event. Together with activation of the central frontal cortex corresponding to the response preparation, we expected that areas related to linguistic processes, e.g. lexical, semantic and phonological, would be activated. The combination of these two activities, preparation for a behavioural response and language-related activation, did effectively differentiate the tasks by shifting central activation towards the areas more involved in each specific linguistic process.

The Italian sample produced results similar to the German group, but showed a significantly higher positive shift at right anterior scalp locations. As already mentioned at the beginning of Section 4, individual and experimental differences between the two samples may account for the larger potential difference found in the right orbito-frontal region.

The semantic task performed by the Italian group was without lateralization and this task is therefore an adequate control condition for the rhyming task in studies on language lateralization. The word comprehension task also involved a semantic process because it required lexical retrieval; such a task also showed little lateralization, but the topographical pattern of activation was different from that evoked by the semantic task. According to several investigations, semantic tasks activate widely distributed networks (Petersen et al., 1988; Wise et al., 1991; Perani et al., 1993; Pulvermüller, 1996; Vanderberghe et al., 1996).

The posterior right parietal cortex is considered to be involved in attentional processes induced by the task (Mesulam, 1990). Nevertheless, it is unlikely that attentional components played an important role in the results discussed in the present study, in particular during observed right temporo-parietal activation, because there was no external stimulation during the analyzed interval. Rather, during the CNV interval, subjects were engaged in internal elaboration of the previously presented stimuli. It is worth noting that two studies performed by means of evoked potentials have shown that semantic processing induces bilateral activation of the cortex (Cobianchi and Giaquinto,

1997) in Italian subjects, or even right temporoparietal activation (the right Wernicke's area) (Abdullaev and Posner, 1997). Both ERP studies are in agreement with our observation of larger right temporoparietal negativity in the semantic task, and an overall lack of lateralization. Thus, similarly to Abdullaev and Posner (1997), we support the view that the right temporal lobe may be involved in semantic categorization of linguistic material.

5. Conclusions

Notwithstanding experimental and linguistic differences in both German and Italian samples the rhyming task induced marked left lateralization of the evoked potentials measured over the frontal and temporal cortex. This was not the case for the lexical or semantic tasks. Rhyme-induced lateralization was observed in both German and Italian subjects, pointing to the cross-language reliability of the paradigm, although it was produced in different stimulus conditions. Thus, rhyming may be particularly suited for studying language lateralization in a variety of conditions such as during development, in language-impaired (e.g. dyslexic) subjects, or in brain-damaged patients such as aphasics. Among the possible applications, the paradigm developed here may serve to study cortical reorganization in aphasics during functional recovery of language. It should be noted that investigations based on evoked potentials are non-invasive, economic (compared to, for example, fMRI or PET), and easily implemented in a clinical context.

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