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Research report

Language lateralization in phonological, semantic and orthographic tasks: A slow evoked potential study

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Abstract

Most of literature on language has shown how different word-classes activate distinct neural networks within linguistic cortical areas. The present investigation aimed to demonstrate that, by means of slow evoked potentials and using the same set of words in different tasks, it is possible to activate cortical networks that are spatially and temporally distinguished. Twenty healthy subjects had to evaluate, in a word pair matching session, whether two words rhymed (phonological task), were semantically related (semantic task) or were written in the same letter case (orthographic task). Slow wave amplitude was computed in three relevant time windows: the last 0.5 s of first word presentation (W1), the initial contingent negative variation (iCNV) and the terminal CNV (tCNV). During W1 and iCNV intervals, both the orthographic and the phonological tasks were left lateralized. Furthermore, the phonological task was more lateralized than the orthographic because of a greater inhibition of the right hemisphere, whereas the orthographic task was characterized by a greater bilateral posterior activation. During the tCNV, only the phonological task remained left lateralized while orthographic and semantic were bilaterally distributed. Although the use of the same set of words tends to activate widely overlapped networks, in the present research task manipulation was effective in demonstrating task dependent differences in brain lateralization. Thus, the present paradigm and the adopted tasks are especially suited for studying deficit and recovery of language in patients affected by linguistic disorders such as developmental dyslexia and aphasia.

Keywords: Language lateralization; Slow cortical potentials; Phonological encoding; Semantic processing; ERPs; EEG

1. Introduction

The functional lateralization of the human brain seems to represent a prerequisite for the full realization of the linguistic potential [28,33,37]. Functional neuroimaging techniques, such as fMRI and PET, have clearly demonstrated that the most steady laterality effects are reliably located over left inferior frontal areas [9,12,19–21,27,36,42,44,50,56,64,67–69]. Nevertheless, although functional techniques provide a very good spatial resolution (fMRI and PET) and a proved measure of the laterality index (fTCD and PET), the time course of cortical activation cannot be studied with precision, a problem which highlights the need of complementary non-invasive methods for the full assessment of language lateralization. It is evident, especially in the linguistic field, the need for distinguishing the different processes that occur across time also within few tens of milliseconds, and that usually in a high spatial resolution picture of brain metabolism appear to be largely overlapped in the temporal dimension (see [43] for a critical review). It is possible, for instance, that lateralization of language is confined, depending on the task and the selected stimuli, to early compared with late phases of word processing, an issue that cannot be addressed with methods based on brain metabolism. Although EEG does not provide a comparable spatial resolution of brain activity, a reliable discrimination of electrical activity at level of gross cortical regions such as anterior versus posterior and left versus right hemisphere can be obtained. Thus, depending on the scientific question it is possible to obtain from EEG reliable and relevant information on lateralization by using special care in the selection of methods and paradigms. Several studies have been carried out using ERPs to analyze the time course and the distribution of the electrical activity over the scalp of a number of linguistic functions, both in adults (e.g. [2,26,34,46,48,54,55]) and in functionally recovered aphasic patients in whom a substantially affected lateralization was

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expected (e.g. [3,5,6,22,23,25,31,63,65]). However, only a few of the quoted investigations have used an ERP paradigm to assess the lateralization in specific linguistic tasks. For example, by using a prime-target matching paradigm, Rugg [54,55] has found in adults a left lateralized slow ERP negativity during a phonological judgement task, whereas Altenmüller et al. [3], as well as Thomas et al. [65] have recorded, during a synonym generation task in aphasic patients, slow negative potentials which were greater over the left than the right frontocentral cortical regions. Other studies have shown how different word classes are able to activate distinct cortical regions within the left hemisphere that are related with specific word functions. For instance, words related to action activate, in addition to linguistic areas, also the motor cortex, whereas visual-related words activate temporal regions where the visual representation of the word is stored; furthermore, different networks are involved in the cortical elaboration of function versus content words [47], and also mass and count nouns are differently distributed across linguistic regions [14]. However, in task-focused experiments, the mentioned word categories cannot be easily balanced for semantic relevance [57], frequency, length, phonology, etc., making it difficult to disentangle their parametric class-specific properties, especially in view of their use in clinical populations with linguistic deficits that include also class-specific deficits. As a further problem, it is necessary to emphasize that, in most EEG studies, electrical activity has been recorded with only a few selected electrodes referred to linked mastoids, thus determining an important bias. Indeed, it is currently well known that the temporal cortex underlying mastoid sites is an active brain structure which is strongly involved in most linguistic processes. Furthermore, the most common eye movement correction method, e.g. the regressive analysis [29,59], tends to remove, together with ocular artifacts, also the electrical activity of anterior cortical regions, thus providing an underestimation of activity from cortical areas (e.g. frontal and temporal) critically involved in language.

The linguistic paradigm of the present research is based on the use of the same sample of concrete words in different tasks, a methodological strategy that should strongly reduce most of the limits listed for other approaches. We have validated an ERP paradigm to test linguistic lateralization in different tasks [4] by using both a language-free scalp reference, that is average reference, and an eye artifact modelling method to optimize the correction of all recorded channels [10,11], including frontal and temporal sites. In that study, we have found in both Italian and German native speakers significant marked left lateralization of the evoked potentials measured over the frontal and temporal cortices during the rhyming task, but not in lexical–semantic tasks [4]. With respect to our past experiment, in the present study we introduced three main innovations. First, we compared three different linguistic tasks, by using the orthographic as more basic control task that better contrast the activity induced by both the semantic and the phonological tasks. Second, we analyzed three specific time intervals, corresponding to different phases of word elaboration, to follow the temporal development of linguistic elaboration. Finally, we selected a group of aged adults with respect to the young adults of the past sample with the aim to verify the generalization of lateralization effect across different ages. In line with prior evidence, the current investigation was carried out to further validate and generalize our CNV language-related paradigm in measuring lateralization of linguistic processes. According to prior findings [4], we expected the phonological task to elicit a greater activation of the left hemisphere and a relative inhibition of the right hemisphere, particularly at level of frontal cortex, whereas the semantic task was expected (starting from EEG rather than from fMRI literature) to induce a bilateral more distributed cortical activity. With reference to the orthographic control task, we foresaw an initial left-lateralized cortical pattern produced by the automatic word elaboration (even though unnecessary to perform this task), followed by a shift of strategy related to the main non-linguistic requirements of the task.

2. Materials and methods

2.1. Participants

Twenty native Italian subjects (seven females, mean age 59.10 ± 7.11 years, range 43–69 years) gave their written consent to participate in the experiment. All subjects were fully right-handed, in average above 90% according to the Edinburgh Handedness Inventory [38]. None of the subjects had been treated for any neurological or psychiatric disorder, nor was under medication. Experimental procedures were approved by the local Ethics Committee.

2.2. Apparatus and physiological recordings

In order to improve our past paradigm, we increased both the number of cortical sites recorded, and the temporal resolution. Thus, electroencephalogram was continuously collected in dc mode, by following the main requirements for high quality dc recordings [7], with a low-pass filter set to 30 Hz, sampling rate of 500 Hz, and amplitude resolution of 0.168 μV/bin. Electrical signals were measured by means of 38 tin electrodes, using two SynAmps amplifiers (NeuroScan Labs, Sterling, USA), 31 mounted on an elastic cap (ElectroCap) according to the International 10-20 system [39]; the other seven electrodes were applied below each eye (Io1, Io2), on the two external canthii (F9, F10), on the Nasion (Nz) and on mastoids (M1, M2; see Fig. 1b). Cz was used as on-line recording reference for the EEG channels, then data were converted off-line to the average reference.

2.3. Stimuli, tasks and procedure

Stimuli consisted of bi- and tri-syllabic Italian content words with average frequency, selected from a dictionary of 5000 written Italian words [16]. Words were visually presented in pairs on a computer screen one at a time, with an inter-stimulus interval (ISI) of 2 s: the first word (W1) remained on the screen for 1 s, the second word (W2 or target) was presented until subjects responded by pressing a keyboard button, in any case not longer than 5 s (Fig. 1a). Word pairs were used in three tasks administered in separated blocks. To avoid psychophysical and word-category systematic effects, the same sample of words was presented as W1 in all tasks, but in different randomized order. Indeed, previous cross-linguistic validation studies showed that the same words activate different neural networks according to the task in which subjects are involved [4,24]. Thus, in the phonological encoding task, participants had to decide, upon W2-target presentation, whether the word pairs rhymed (e.g. brodo-chiodo [broth-spike]) or not (e.g. neve-corda [snow-rope]). In the semantic task, subjects had to decide whether the target word W2 was semantically related to the first (e.g. brodo-minestra [broth-soup]) or not (e.g. neve-sveglia [snow-alarm]). In the orthographic control task, participants were asked to press a "yes" button if both words were written in the same types (either lower or upper cases, i.e. BRODO-FRUTTA [BROTH-FRUIT]), or a "no" button if the two words were written in different types (lower versus upper cases or vice versa, i.e. neve-