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# Rapid and slow brain systems of abstract and concrete words differentiation

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**Abstract**

Previous studies have repeatedly found that late (300–800 ms) components of event-related potentials (ERP) reflected semantic analysis, i.e. the differentiation between abstract and concrete words. However, the human brain may detect the meaning of the words much earlier. This study investigated the brain mechanisms of the processing of abstract and concrete written words in four experimental conditions: i) Simple Reading, during which volunteers were required to silently read words; ii) Simple Classification, during which volunteers were required to classify the presented word into the abstract and concrete categories; and iii) Cued and iv) Uncued Selective Classification conditions, during which subjects had to classify only the words typed in a particular colour. 19-channel EEG was recorded during the experiment from 13 subjects. The ERP to abstract and concrete words differed not only at the late but also at early (40–100 ms) latencies in the Simple Reading and Classification conditions, as well as for the words that should not be explicitly classified in the Cued Selective Classification condition. This means that semantic analysis can occur in a manner which is both very rapid and implicit. Moreover, increasing task demands can even suppress this rapid semantic analysis. The functional microstate analysis revealed a topographical difference in response to abstract and concrete words, which indicated that at least partly distinct brain networks are involved in the processing of words during both early (implicit differentiation) and late (explicit classification) latencies.


*Keywords:* Word processing; Event-related potentials; Brain semantic systems; Implicit and explicit brain functions; Microstates analysis

## 1. Introduction

The processing of written words consists of multiple levels, including orthographic processes involved in the visual analysis of letter and words forms, phonological processes involved in the phonemic analysis of words, and semantic processes involved in the conceptual analysis of words. Typically, models of word reading postulate a sequential processing of written word features. The common view is that the semantic processing, such as the differentiation of concrete from abstract words, is reflected in the late component (N400) of event-related potential (ERP) (Friederici, 2004; Bentin et al., 1999; Nittono et al., 2002; West and Holcomb, 2000).

However, there is a large body of evidence that a faster form of semantic analysis is also possible. During rapid serial visual presentation (RSVP), when words are presented sequentially, one-at-a-time as text at the same location within the visual field, the speed of silent word reading and comprehension has been shown to be as fast as 1652 words/min (about 36 ms per word) (Rubin and Turano, 1992). Evidence from experiments that have used masked visual stimuli has also indicated that rapidly-presented words are processed semantically, even when those words go unrecognized. Emotional words presented below the individual threshold of duration for identification (15–40 ms), have been shown to still elicit an enhanced skin conductance response (SCR), in a manner which was not seen with neutral words (Silvert et al., 2004). Similar results have been revealed using a priming paradigm. It was shown that undetectable masked words were able to semantically prime the words presenting afterwards (Ruz et al., 2003).

The behavioural data, as well as skin conductance response data, do not directly indicate that the semantic analysis takes place within the first 100–200 ms. It may be argued that information enters the brain, but semantic analysis occurs later, in parallel with other processes. Some evidence against this

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delayed parallel processing explanation stems from Eye Movement (EM) studies. The average duration of a fixation is roughly 250 ms, but the time for the motor programming that is necessary for the next eye movement takes about 50–150 ms (Sereno and Rayner, 2003). This duration of a fixation varies as a function of lexical and semantic difficulty and, at a certain level, lexical, as well as semantic, access is necessary for initiation of EMs. Errors in the text have an immediate effect upon EMs (Carpenter and Dahneman, 1981; Daneman and Reingold, 1993), and thus would seem to be detected straight away during the fixation, rather than being detected later on, as for instance could occur at the end of a clause or sentence.

Early differences in brain activity elicited in response to the words of different categories offer corroborative evidence for an ultra-rapid semantic analysis. Influences of the semantic meaning of the word upon brain activity begin as early as 80 ms post-stimulus (Skrandies, 1998). For instance the distribution of ERP components elicited by emotional and neutral words have been shown to exhibit a distinct topography at as early as 100–140 ms (Ortigue et al., 2004). Visually-presented nouns and verbs, passively viewed, elicited different electric potential maps already at 116–172 ms (Koenig and Lehmann, 1996). Multiple recordings from a single subject have shown that already at the latency of 100 ms significantly stronger neuromagnetic responses were elicited by words with strong multimodal semantic associations than by other word material (Pulvermuller et al., 2001). Further, within the immediate semantic priming paradigm, an early difference (100–150 ms) between brain activation for related and unrelated words has also been demonstrated (Michel et al., 2004).

Corroborative evidence of a slightly different sort stems from a line of research which has shown that the categorisation of complex visual objects is possible within the first 100 ms after the onset of the presented stimulus. This categorisation process would seem to be both involuntary and attention-independent (VanRullen, Thorpe, 2001; Seeck et al., 1997, Mouchetant-Rostaing et al. 2000, Eger et al., 2003).

In these studies, where this early semantic effect has been found, the level of task difficulty was typically very low. That is, the task was a passive paradigm with a requirement for silent reading (Skrandies, 1998; Koenig and Lehmann, 1996), or either a lexical decision or recognition task (Ortigue et al., 2004; Michel et al., 2004; Pulvermuller et al., 2001). However, in traditional ERP studies of semantic analysis, more demanding cognitive tasks have also been used. For example, Nittono et al. (2002) asked volunteers to rate the imageability of a word (1: difficult to image, 5: easy to image). West and Holcomb (2000) used a truthfulness judgment task. They found that the ERP difference between abstract and concrete words started only ca. 350 ms after the onset of the presentation of the word. This late ERP difference was found only when the judgment required image generation or semantic decision. By contrast, this late ERP difference was not found when there was only the requirement of evaluation of surface characteristics upon a letter search task (West and Holcomb, 2000).

The goal of this investigation was to examine the brain systems involved in implicit and explicit differentiation of the words according to their abstractness/concreteness. Of particular interest was the influence of an attentional modulation to differentiation of abstractness/concreteness. In this study the demands of the task were varied by introducing the Cued and Uncued selective classification tasks. Together with traditional ERP analyses, this investigation also employed a microstate analysis, which is a method for the segmentation of brain activity into the stable states with similar topographical distribution (Michel et al., 1999). The method offers a technique with which it could be possible to distinguish the activity of separable brain systems that subserve the processing of abstract and concrete words. That is, a distinct brain topography could reflect that partially distinct neuronal populations are activated during the processing of abstract and concrete words. Given the activation of neuronal populations can be related to the mental processing of words, the use of such a method could thus distinguish between two theories of abstract and concrete words processing. Dual-coding theory (Paivio, 1971) assumes that there are two systems of word analysis: a "linguistic" system, which deals with verbal information, and an "imagistic" system, which deals with imaginable information. Abstract words are processed only by "linguistic" system, whilst concrete words are processed by both "linguistic" and "imagistic" systems. Accordingly, different brain topographies of ERPs to abstract and concrete words would be consistent with this dual-coding theory. The context availability theory (Schwanenflugel et al., 1992; de Groot, 1989) assumes that words are processed by a common verbal system, but due to denser word associations for concrete than for abstract words, this system is activated more intensively by concrete words. However, a similar brain topography in response to abstract and concrete words would be predicted by context availability theory.

## 2. Materials and methods

### 2.1. Volunteers

Thirteen healthy native Russian speakers took part in this experiment. Volunteers gave their informed written consent after the nature of the study was explained to them. Two subjects did not understand correctly the instruction for the word classification as revealed from their behavioural responses and thus their data were excluded from all further analyses. All the remaining volunteers reported that they were right-handed, had normal colour vision and also reported that they did not have a reading disability. These remaining volunteers (8 men and 3 women) were aged 22–45 years.

### 2.2. Stimuli

Volunteers were seated in a comfortable armchair 170 cm from the 14 in. monitor within an electrically-shielded room under dim conditions of artificial lighting. The stimuli were words (letter size $2.9 \times 3.1$ cm, corresponding to a visual angle of ca. 1°), half of which were written in green (RGB: 0 150 0) and half in lilac (RGB: 128 0 128). The words were presented in the center of the black screen (size 20, 5*28 cm) sequentially in random order using the "Presentation v.9.12