NeuroImage 91 (2014) 252–261

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Lexical access and evoked traveling alpha waves

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ARTICLE INFO

Article history:
Accepted 20 January 2014
Available online 30 January 2014

Keywords:
P1
Alpha
Traveling-wave
Lexical access
Semantic memory

ABSTRACT

Retrieval from semantic memory is usually considered within a time window around 300–600 ms. Here we suggest that lexical access already occurs at around 100 ms. This interpretation is based on the finding that semantically rich and frequent words exhibit a significantly shorter topographical latency difference between the site with the shortest P1 latency (leading site) and that with the longest P1 latency (trailing site). This latency difference can be described in terms of an evoked traveling alpha wave as was already shown in earlier studies.

Introduction

The aim of the present study is to investigate whether topographical latency differences of the P1 component of the visual event related potential (ERP) are associated with a specific type of cognitive process. Our hypothesis is that they might reflect early access to semantic memory. The motivation for this hypothesis is based on three different lines of evidence. The first refers to the observation that the P1 has a frequency characteristic in the alpha range and behaves like an evoked alpha traveling wave (Fellinger et al., 2012; Klimesch et al., 2007a) during access to semantic memory (Fellinger et al., 2012; Klimesch, 2011). The second is related to findings about the functionality of alpha (Klimesch, 1997, 1999, 2012) suggesting that alpha oscillations are associated with controlled knowledge access. The third line of evidence concerns predictions of a semantic network model (the connectivity model, cf. Klimesch, 1994) that describes the differential influence of the number of semantic features (representing the complexity of a semantic code) on memory access.

Semantic memory may be considered the core of long-term memory which represents the meanings of all kinds of information such as the meanings of words, geographic relationships, or mathematical knowledge (Anderson, 1983; Collins and Loftus, 1975; Klimesch, 1994). Activation of the semantic memory network is described in terms of spreading activation. One critical aspect (here) is how complexity influences the speed of spreading activation. Traditional models such as ACT or ACT* (Anderson, 1983) assume that activation hitting a node with many links (leading off from that node) is weakened (and processing speed is slowed down) proportionally to the number of links. This processing disadvantage became well-known as the fan effect. According to these models, complex codes are processed at a slower speed than less complex codes. The connectivity model (Klimesch, 1994), however, makes differential predictions that depend on the properties of spreading activation. In divergent processing stages complexity is associated with a slowing, but in convergent stages with an acceleration of spreading activation (see further below).

Short latency EEG responses around about 100 ms (such as the P1 and evoked alpha) may reflect early stimulus categorization that emerges as interaction or synthesis between bottom-up and top-down processes. The processing of visual information may be characterized by four consecutive time windows that are associated with different ERP components, sensory encoding (reflected by the C1at about 80 ms), early categorization (reflected by the P1at about 100 ms), stimulus identification (reflected by the N1 at about 150 ms) and conscious stimulus evaluation (reflected by the P3 at about 300 ms). In this context, early categorization is a process that precedes and enables identification and later processes (for a review cf. Klimesch, 2011).

In the present study we do not primarily focus on spreading activation within semantic memory but on the access to semantic memory, which is closely linked to lexical access (i.e., access to the graphemic/phonetic code of words). One essential question here is what kind of processes enables access to memory in general and to the lexicon in particular. Our hypothesis is that early categorization of stimulus information (regarding lexical and semantic information in our case) is the 'key' for memory access. We assume that the P1 may be considered as the EEG correlate reflecting this early categorization process that enables access to lexical and semantic memory.

Abbreviations: +NOF, high number of features; −NOF, low number of features; WFREQU, word frequency; LATDIFF, latency difference between trailing and leading electrode.

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http://dx.doi.org/10.1016/j.neuroimage.2014.01.041

Research on evoked EEG activity has demonstrated that sublexical and lexical features show differential effects already in the time window of the P1component of the visual ERP. For example several studies have shown differences in evoked ERP amplitudes at around 100 ms in response to orthographic neighborhood size, orthographic typicality, word length, letter n-gram frequency, word frequency, as well as semantic factors (see Dien, 2009 for a review; Hauk et al., 2006a,b; for a review Hauk and Pulvermüller, 2004; Hauk et al., 2009; Segalowitz and Zheng, 2009). Early differences in evoked activity in response to word length and frequency were also observed in MEG studies in the time window of the P1 (cf. e.g., Assadollahi and Pulvermüller, 2003). These findings suggest that lexical access occurs early, at around 100 ms. Other research groups, however, emphasize that early encoding processes of visually presented words are associated with a bottom-up analysis of visual features that enable access to visual word form (or low level feature) representations but not necessarily access to the lexicon (e.g. Dehaene et al., 2005; Pylkkänen and Marantz, 2003). These groups refer to evidence for a late time window of lexical access, at around 350 ms (cf. e.g., Pylkkänen et al., 2002; Solomyak and Marantz, 2009).

Evidence for early or late lexical access may depend largely on task type (e.g., requiring lexical or semantic decision), and thereby on the extent to which top-down strategies can be used to speed up encoding and/or decision/categorization processes. If sensory and (sub-) lexical features are closely interwoven, top-down processes can be effective even at low levels of stimulus processing. Evidence for this view is supported by an interesting corpus analysis of nouns and words showing phonological typicality effects (Farmer et al., 2006), thereby demonstrating that different lexical categories are already associated with 'low level' phonological properties.

Preliminary evidence for our hypothesis, that an evoked traveling alpha wave reflects access to semantic memory, comes from a recent study by Fellinger et al. (2012). The results showed that the speed of the traveling alpha wave (which coincides with the appearance of the P1) is related to semantic categorization speed in a way that a slow traveling movement of the P1 is significantly associated with a shorter reaction time (RT). Subjects had to categorize black and white pictures (whether showing a landscape or building). The physical properties of the pictures were kept constant by adjusting luminance, contrast and magnitude spectra. This procedure reduced or eliminated differences in surface features between the two categories but at the same time made the pictures rather difficult to recognize. The general conclusion was that the observed traveling alpha waves reflect access to semantic memory and that the speed of traveling is related to the complexity of this process — a complex process slows down traveling; a less complex process may speed it up. Considering the fact that the pictures were rather difficult to categorize, the interpretation was that a slow traveling process reflects a situation where many different semantic features are accessed because the meaning of the picture is complex and rather difficult to assess. Why such a process is associated with shorter RTs is rather difficult to answer. It could for instance be that a more complex process enables a more accurate categorization process which then operates to speed up RT. A more specific interpretation may be derived from the connectivity model (see the respective discussion in the last paragraphs of this section) which assumes that complexity slows down early access processes to semantic memory, but speeds up processes during later stages within semantic memory. In the study by Fellinger et al. (2012), however, no stimulus properties such as picture norms or related word norms were at hand to test this interpretation regarding the influence of stimulus complexity.

Here we proceed from the well-established finding that a variety of variables, such as word frequency, word length, as well as the number of semantic features (NOF) influence semantic categorization speed (as measured by RT). Several studies have shown that high word frequency and short word length result in faster lexical decision times (for a review cf. Brysbaert et al., 2011; Yap and Balota, 2009). Regarding semantic neighborhood density, similar findings were obtained. Pexman et al. (2003) found that high NOF words are easier to categorize in a sense that they speed up RT (also see Buchanan et al., 2001; Yates et al., 2003) compared to low NOF words. We predict that if the P1 reflects early categorization allowing memory access and if the traveling movement of the P1 is related to the ease of the access process, a higher traveling speed for words that are easy to categorize should be found.

In the present study we used a living/non-living semantic decision task. Subjects were asked to give a 'yes' response to words representing a living object and a 'no' response to words denoting a non-living object. We assume that a semantic decision is based on a network search that aims to detect common features between the semantic code of the to be judged subordinate concept and that of the superordinate concept. According to the connectivity model proposed by Klimesch (1994), NOF – representing the complexity of a semantic code – speeds up semantic categorization, which is described as spreading activation between two (or more) codes. This processing advantage of NOF is, however, restricted to certain activation stages. In a simple case, when a single code is accessed, three activation stages – one with divergent and two with convergent activation – can be distinguished. In a first stage – the access stage – divergent activation flows from the concept node (also termed access node) to all directly connected feature nodes. During this access stage, NOF may lead to a slowing due to the dissipating influence of a fan effect (cf. detailed discussion in Klimesch, 1994 in chapter 8.4). In a second stage, activity flows from each feature node to all other feature nodes. At the end of this second activation stage convergent activation accumulates at each feature node. In a third stage, activity flows back and converges at the access node. The processing advantage occurs at the end of the second and third stage as activity converges and accumulates at the respective nodes (i.e. at the feature nodes in the second stage and the concept node in the third stage). The convergent activity (or echo) that spreads back to the access node is termed as indirect activation. Its amount is proportional to the number of features and its arrival at the access node signals the end of the search process. The time that indirect activation needs to arrive at the access node is reciprocal to its strength. Because activation strength depends on NOF, a search is faster for codes with many features as compared to codes with only a few features. This example characterizes the 'standard case', where a single code is accessed.

In a semantic categorization task, spreading activation between two codes is assumed. For a 'yes' response in a living/non-living judgment task (used in the present study) the critical prediction is that preactivation (operating in the second and third activation stage) speeds up spreading activation. Because the superordinate concept remains the same through the entire task, a top-down controlled processing mode can be established that activates semantic features which are typical and very common for living objects. Thus, the search process, emanating from the subordinate concept node will meet already preactivated feature nodes in the second activation stage that are shared between the two codes. The amount of preactivation increases with NOF because the activity of the preactivated node(s) is increased by activity flowing to this node from all remaining nodes. In the third stage, indirect activity (strengthened by preactivation) flows back to the access node. Due to the influence of preactivation, a positive search result for a 'yes' response is obtained faster than for a single code. It is important to note that an NOF-related processing advantage is predicted for the second and third activation stage but not for the first stage which reflects access to semantic features.

For a 'no' response, the first stage of activation is identical with that for a 'yes' response. Here too, the features of the (subordinate) concept code have to be accessed. But then the situation is quite different, because the two codes (that of the sub- and superordinate concept) will not share common features. According to the connectivity model, the lack of arrival of preactivated indirect activation is the criterion for