Neuropsychologia 47 (2009) 3162–3173

Contents lists available at ScienceDirect

Neuropsychologia

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

Cognitive association formation in episodic memory: Evidence from event-related potentials

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ARTICLE INFO

Article history:
Received 10 March 2009
Received in revised form 12 July 2009
Accepted 24 July 2009
Available online 3 August 2009

Keywords:
Dm
Subsequent memory effects
Late wave
N425
P555
Partial least square

ABSTRACT

The present study focused on the processes underlying cognitive association formation by investigating subsequent memory effects. Event-related potentials were recorded as participants studied pairs of words, presented one word at a time, for later recall. The findings showed that a frontal-positive late wave (LW), which occurred 1–1.6 s after the presentation of the second word of a pair during study, was associated with later paired associate recall. The observed LW likely reflected cognitive association formation processing. Paired associate recall was also associated with a larger P555 to each word of a pair, likely reflecting the encoding of each individual word of a pair, which necessarily precedes association formation between the two words. Moreover a larger N425 was elicited by pairs that were encoded in a low context-similarity condition compared to that of a high context-similarity condition, likely reflecting semantic integration. Minimum norm source analyses showed that the likely sources of these ERP effects changed dynamically in time: a widespread fronto-temporo-parietal activation during the N425 was followed by a fronto-temporal activation during the P555, and finally by a left prefrontal activation during the LW.

1. Introduction

We often remember through associations. For example, when we hear a specific song we may vividly remember an episode from the last vacation we spent in the Caribbean, or perhaps our first kiss. Understanding how cognitive associations between different memoranda are formed during encoding, particularly when and where in the brain, remains a classic problem in memory research. The present study examined cognitive association formation by replicating and extending the previous work on subsequent memory effects using event-related potentials (ERPs). The subsequent memory paradigm is commonly used to study how information is encoded into memory. In this paradigm brain responses are measured while participants are presented with to-be-remembered items. Afterwards participants are asked to retrieve these items. The brain responses are then sorted and averaged according to whether the corresponding item was subsequently retrieved or not. The brain responses to subsequently retrieved and non-retrieved items can then be compared to reveal the location and timing of the brain activity that occurs during effective encoding.

The use of paired associates provides an opportunity to study not only the encoding of individual words but also the associative processes that occur at study. In order to separate the encoding of the individual words from the association formation, the words can be presented sequentially. If they are presented together, as in the typical procedure in the experimental psychology laboratory (Lockhart, 2000; Weyerts, Tendolkar, Smid, & Heinze, 1997), the brain responses recorded for the encoding of the first word, the encoding of the second word, and the association between them, are inextricably bound together. However, if the words of a pair are presented sequentially, it is possible to record the encoding of the first word separately from the other components, and then use the evidence thus obtained to sort out the encoding of the second word from the cognitive association formation process(es).

In a previous study of cognitive association formation by Kounios, Smith, Yang, Bachman, and D'Esposito (2001), participants classified pairs of words at encoding according to whether the association was formed through (1) conceptual integration or (2) simple juxtaposition. Each word of a pair was presented sequentially. Participants were later asked to retrieve the order of the words of a pair. The results showed that for pairs of words that were associated through conceptual integration, sustained ERP positivity after

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doi:10.1016/j.neuropsychologia.2009.07.015

the second word was greater for those pairs whose order was later retrieved more quickly. The opposite pattern was observed for pairs that were associated by juxtaposition, suggesting that different neural mechanisms underlie these two strategies of association formation. However, Kounios and colleagues only analyzed successfully retrieved pairs according to order retrieval speed, which is an indirect measure of the effectiveness of association formation.

In the first ERP study that investigated subsequent memory effects using paired associates (Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980), participants judged whether two words of a pair were the same or different based on orthographic, phonemic, or semantic attributes. Each word of a pair was presented sequentially. Participants were then tested on recognition for the second word of a pair. Semantic processing led to the highest percentage of recognized words, followed by the phonemic and then the orthographic comparisons. In three subjects, judgment-task waveforms were averaged on the basis of subsequent recognition. Subsequently recognized words elicited a larger late positive component (LPC) and slow wave compared to subsequently unrecognized words. Unfortunately, these data were not statistically analyzed.

Other studies have found similar ERP effects for the recognition and recall of single words (for reviews see Donchin & Fabiani, 1991; Johnson, 1995; Rugg, 1995). In one such study (Karis, Fabiani, & Donchin, 1984), subsequently recalled words elicited greater positivity compared to subsequently non-recalled words, with a peak latency of 520 ms. The topography and time-course of this effect varied as a function of the encoding strategy that was used. For participants who used rote rehearsal strategies, the amplitude of the parieto-central P300 elicited by subsequently recalled words was larger than that of subsequently non-recalled words (Karis et al., 1984; also see Fabiani, Karis, & Donchin, 1986). For participants who used elaborative rehearsal strategies, a frontal-positive slow wave, which began around 500 ms and slowly increased over the next several hundred milliseconds, was larger for subsequently recalled, compared to non-recalled, words (also see Fabiani, Karis, & Donchin, 1990).

Paller, Kutas, and Mayes (1987) examined ERPs during an incidental memory paradigm. They found greater parietal positive activity in the 400–800 ms latency range for subsequently recalled and recognized words, compared to subsequently non-retrieved words. Paller et al. referred to the difference between ERPs to subsequently retrieved and forgotten words as 'Dm' and defined it operationally as "any ERP Difference based on later memory performance". They found that Dm could not be accounted for solely in terms of changes in the typical P300 amplitude, since the Dm was largest for the semantic tasks over the anterior scalp area. Further, Dm scalp distribution for words (Friedman, 1990) and faces (Sommer, Heinz, Leuthold, Matt, & Schweinberger, 1995) are significantly different from that characteristic of the P300. Thus, although Dm and the P300 may overlap temporally, the topographic distributions suggest that the two have different brain origins.

In addition to the parietal P300 and frontal-positive slow wave Dm effects, other studies have revealed a left fronto-temporal negative Dm around the same time as the P300. For example, Mangels, Picton, and Craik (2001) found a fronto-temporal N340 that was larger for subsequently recognized, compared to unrecognized, words. However, the N340 did not differentiate between items based on Remember (R)/Know (K) judgments (Tulving, 1985; also see Friedman & Trott, 2000; data reanalyzed in Friedman & Johnson, 2000).

The results of the aforementioned studies and the extant literature indicate distinct encoding processes: whereas the posterior positivity and fronto-temporal negativity may reflect encoding processes that enable subsequent item retrieval without additional contextual details, long lasting frontal positivity may index elaborative encoding processes that enable subsequent retrieval with rich contextual details.

In the present study we investigated subsequent memory ERP effects with paired associates, extending the previous literature by examining the Dm effect for paired associates. We did so by focusing on the brain responses recorded after the presentation of the second word of a to-be-learned pair during the encoding phase of the experiment, when cognitive association formation is likely to occur. Furthermore we did so under two experimental conditions in which the subjects' behavioral performance, for identical studied items, was expected to vary greatly because of differences in the to-be-learned pairs' intra-list context. In the present study, the ERP response that followed the second word of a pair was examined to see whether there are any ERP correlates for the successful cognitive association formation between the two words. Extrapolating from the literature on Dm effects reviewed above, we hypothesized that subsequently recalled pairs, compared to non-recalled pairs, would be associated with a larger frontal-positive component.

Paired associate learning is enhanced when each pair in a list belongs to a different conceptual category compared to when all pairs in the list belong to the same conceptual category. This effect of context was demonstrated by Bower, Thompson-Schill, and Tulving (1994) in a study where participants were presented with pairs composed of items from the same conceptual category. Consequently, the participants in this study were able to predict the category of the target when they were given the cue during test. The effect of context on recall may likely be related to the distinctiveness of each pair in a given list in relation to all other pairs in the list: an increase in distinctiveness would lead to a decrease in response uncertainty to a given cue and less interference.

In the present study, we sought to examine further whether cognitive association formation varies as a function of intra-list encoding context. Based on the extant literature, we hypothesized that paired associates in the Different condition would be better recalled than those in the Same condition. Moreover, we sought to examine differences between the evoked potentials recorded for the two context conditions (Same and Different) during encoding. The N400 is a negative ERP component that is typically observed over the centro-parietal regions of the scalp, and has been observed to be larger to words that deviate from the semantic context compared to those that do not (Federmeier & Kutas, 1999; Kutas & Hillyard, 1980; Kutas & Hillyard, 1982). Based on the existing literature, we predicted that items in the Different condition, where intra-list semantic similarity was low, would elicit a larger N400 compared to items in the Same condition, where intra-list semantic similarity is relatively higher. The present study was set up to answer the question of whether subsequent memory ERP effects for cognitive association formation vary as a function of intra-list context manipulation. However, since we did not find any past studies that we could soundly ground a relevant hypothesis upon, this portion of the study was exploratory, without a specific a priori hypothesis.

2. Methods

2.1. Participants

Fourteen healthy, young adults (7 female; mean age: 24, range: 19–32; first language: English) participated in this experiment. All subjects had normal or corrected-to-normal vision and no history of neurological or psychiatric disorder. The study was approved by the Baycrest Research Ethics Board and all subjects provided written informed consent prior to the experiment. The data from two subjects were discarded: one of these subjects had too few trials in one of the conditions to allow ERP analysis, and the other subject had large movement artifacts throughout the recordings. As a result, ERP averages were obtained from 12 participants.