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Neuroscience Letters 345 (2003) 157–160

Neuroscience Letters

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Novel concepts mediate word retrieval from human episodic associative memory: evidence from event-related potentials

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Received 29 November 2002; received in revised form 17 April 2003; accepted 23 April 2003

Abstract

Effects of conceptual fusion on episodic associative retrieval were examined. Subjects attempted to fuse sequentially displayed (800 ms offset) word pairs; pairs subjects were unable to fuse were instead considered associated by juxtaposition. Next, dense-array event-related potentials (ERPs) were recorded while the pairs were redisplayed, half reversed in order. Subjects pressed a button to indicate whether each pair was presented in the previous order. Behavioral results showed that retrieval of fused pairs was faster and more accurate than for juxtaposed pairs. ERP topography to the first word of fused pairs was different from juxtaposed pairs, indicating that fusion can mediate associative retrieval of constituent items. Estimates of current source density at the cortical surface showed that fusion-mediated retrieval elicited left inferior-prefrontal/anterior-temporal activity not typically observed in episodic memory retrieval studies.

Keywords: Memory; Memory retrieval; Associative memory; Event-related potentials; Brain mapping; Left inferior prefrontal cortex

The classical view of associative memory is based on *juxtaposition* or *contiguity*, in which linked ideas remain distinct [2]. The Gestalt theorists' alternative view is that through juxtaposition items can merge to form a holistic episodic conjunction or compound in which the constituent items are symmetrically associated [12]. A third hypothesis is that ideas can be associated through *conceptual fusion* (e.g. *computer* + *virus* = *computer-virus*) [2,5,8,13]. The result is a novel concept rather than a simple merging of two items to form an episodic compound (as in *computer-and-virus*). These views are not mutually exclusive, as all three mechanisms may be operating.

A recent study [13] tested the hypothesis that encoding novel, conceptually fused, word pairs into episodic memory would involve brain activations different from those involved in encoding pairs that could not be fused and were, by default, associated only by juxtaposition. These two types of associations elicited different patterns of behavioral performance, event-related potential (ERP) polarities, scalp topographies, and estimated brain sources, supporting the hypothesis that conceptual fusion involves a distinct type of associative encoding.

The present study examined the effects of conceptual fusion on episodic associative retrieval. We tested the hypothesis that the retrieval of conceptually fused word pairs involves brain mechanisms different from those involved in retrieving pairs associated by juxtaposition. A description of the methods has been published recently [13] and is summarized here.

We used a task requiring subjects to remember on each trial the order in which a previously presented pair of words was displayed [10]. This task capitalizes on an important characteristic of fusion associations, namely, that they are semantically asymmetrical (e.g. *computer-virus* ≠ *virus-computer*), whereas associations not based on fusion are semantically symmetrical (e.g. *computer* + *virus* = *virus* + *computer*) [13]. Prior to each test phase, participants viewed novel pairs of concrete, high-frequency nouns displayed sequentially (200 ms duration, 800 ms between onsets). For

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0304-3940/03/$ - see front matter © 2003 Elsevier Science Ireland Ltd. All rights reserved.
doi:10.1016/S0304-3940(03)00517-2

each pair, the participants' task was to attempt to conceptually fuse the words (using the presentation order) to form a single distinct concept, as in a compound noun [6,13,18]. Conceptual fusion was explained to participants, who were given examples and practice. Their task was to indicate whether they had successfully fused each pair by pressing one of two buttons before the 4 s deadline. The test-phase procedure was identical to the encoding phase except that (a) the original presentation order was reversed for half of the pairs, (b) the participants' task was to press one of two buttons to indicate whether each test pair was presented in the same or reverse order compared to the encoding phase, and (c) the overall order in which the pairs were presented was randomized. ERPs were measured (right mastoid reference) with 64 electrodes (digitized at 250 Hz, 0.02–50 Hz).

Eight right-handed, native English speakers (18–22 years old) participated (after informed consent) in three study-test sessions on separate days. Prior to each encoding phase, they were told about the subsequent memory test for word order. ERP data from one subject were omitted due to equipment problems. The study was approved by the University of Pennsylvania Institutional Review Board.

ERP averages for the fused versus juxtaposed and same versus different order conditions were computed from correct-response trials using a 100 ms prestimulus baseline. Each word pair was identified as fused or juxtaposed based on that participant's encoding-phase judgment.

Laplacians and inward continuations of the ERPs were computed with EMSE 4.2 (http://www.sourcesignal.com) using published parameters [16]. A realistic head model was derived from the structural MRI of one subject co-registered to digitized electrode locations. Electrodes were placed for each subject relative to standard head landmarks (nasion, inion, and preauricular notches), spatially normalizing the results across subjects. All statistical tests used a 0.05 significance criterion without corrections for multiple comparisons, as all tests were nonindependent.

During encoding, participants' button-press responses indicated that they fused 60% of the pairs; pairs that were

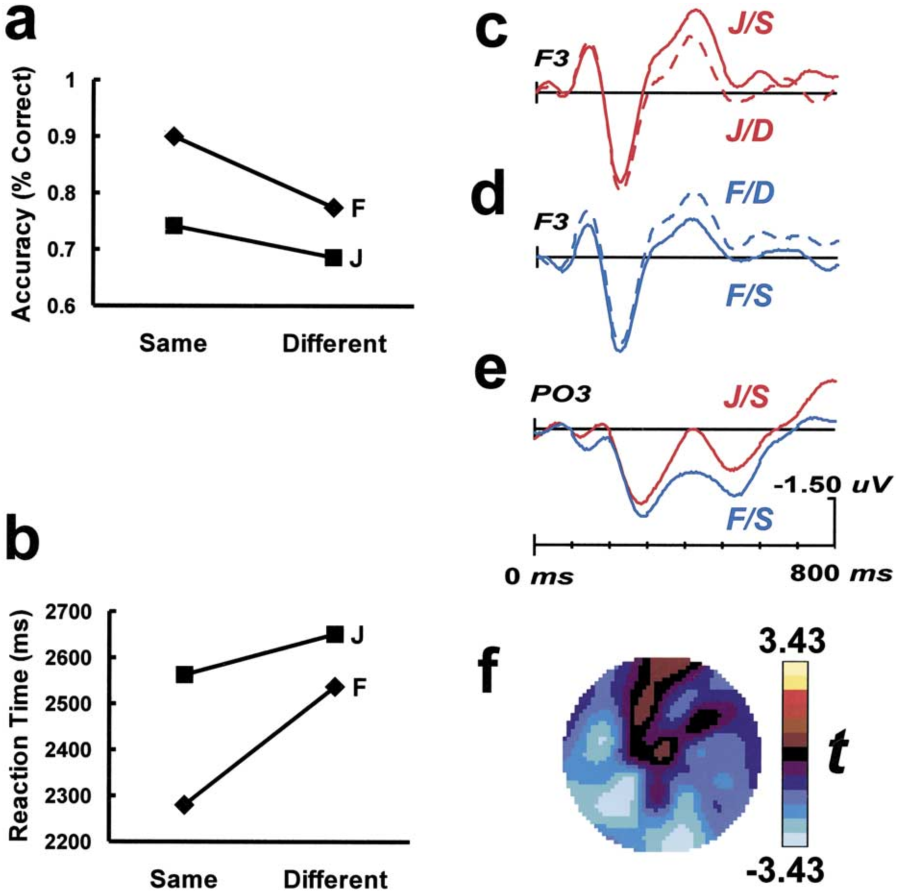

Fig. 1. Behavioral and ERP results. (a) Mean response accuracies (percent correct) to previously fused (F) and juxtaposed (J) word pairs that were presented at test in either the same or different order from the original presentation order used during encoding. (b) Corresponding reaction times in milliseconds (ms). (c–e) ERPs to the first word of each pair (which onsets at 0 ms, each x-axis tick representing 100 ms). Negative amplitude in microvolts (μV) is plotted on the y-axis. (c) ERPs recorded at a left-frontal (F3) electrode for the first word of juxtaposed (J) pairs presented in the same (S, solid line) order as at encoding and for the first word of juxtaposed pairs presented in the different order (D, dashed line). (d) Results for fused (F) pairs. (e) Comparison of the juxtaposed/same-order and fused/same-order ERP waveforms at a left parietal-occipital (PO3) electrode. (f) A statistical parametric map plotting t-scores for the comparison of the same-minus-different order effect for fused and juxtaposed pairs for the 500–796 ms after first-word onset. The map is a schematic view of the top of the head, with the front of the head at the top.

not fused were, by default, considered associated by juxtaposition. Fusion responses (1782 ms) were faster than juxtaposition responses (2169 ms; $t_7 = 5.12$, $P = 0.001$).

Fusion facilitated both speed and accuracy of test-phase order recognition (Fig. 1a,b), even though participants spent less time judging pairs that they fused than pairs that they were unable to fuse. During the test phase, response accuracy was greater for fused (85%) than for juxtaposed pairs (72%; Fig. 1a), in contrast to previous work showing that preexisting semantic association inhibits order recognition [10]. This was substantiated by a 2 × 2 (fused/juxtaposed × same/different-order) repeated-measures analysis of variance (ANOVA) which showed a main effect of fusion/juxtaposition ($F_{1,7} = 32.95$, $P < 0.0001$). The order and interaction effects were nonsignificant. Test-phase responses were faster for pairs in the same order as at encoding (2471 ms from first-word onset) than for pairs in the reverse order (2662); responses were faster for fused (2347) than for juxtaposed (2586) pairs (Fig. 1b). The corresponding ANOVA yielded main effects of fusion/juxtaposition ($F_{1,7} = 44.78$, $P < 0.001$) and order ($F_{1,7} = 46.34$, $P < 0.001$), and a fusion/juxtaposition × order interaction ($F_{1,7} = 10.02$, $P = 0.016$). There was a larger order effect on fused pair reaction times than on juxtaposed ones (Fig. 1b), consistent with the notion that fusion associations are more asymmetrical than juxtaposition associations.

ERPs differentiated test pairs presented in the same order from those presented in the reverse order even before the onset of the second word of each pair (Fig. 1c,d). At some scalp sites (e.g. the left frontal electrode shown in Fig. 1c,d), the order factor had opposite effects on (untransformed) ERP amplitudes for juxtaposed and fused pairs, indicating that the onset of the first word of the pair initiates processes sensitive to both change in word order and association-type. This sensitivity to association-type is illustrated in Fig. 1e, which contrasts ERP waveforms for juxtaposed and fused same-order pairs at a left parietal-occipital electrode.

This was substantiated by Fig. 1f which shows the topographic distribution of t-scores for the comparison of the same- minus different-order effects for fused and juxtaposed associations (after normalization [15]) for the 300 ms epoch preceding presentation of the second word. This comparison shows significant differences over left frontal, temporal, parietal, and right parietal and occipital areas, indicating different patterns of brain activity corresponding to the retrieval of fusion and juxtaposition associations.

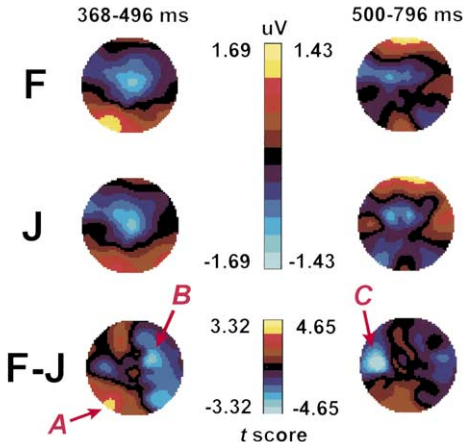

Fig. 2. Statistical parametric maps comparing normalized ERP topographies for fused and juxtaposed words. The left column shows ERP topographies for the 368–496 ms time-window after first-word onset; the right column shows results for 500–796 ms. The top row shows the distribution of ERP voltages (μV) to fused first words; the second row shows results for juxtaposed first words. The bottom row shows statistical parametric maps (t-scores) of the comparison of (normalized) ERP topographies for fused and juxtaposed words. Arrows indicate foci of effects.

Statistical parametric maps of the voltage differences between the same-order fusion and juxtaposition conditions (after normalization) for two epochs (368–496 and 500–796 ms) are shown in Fig. 2. From 368 to 496 ms, there were significant differences between the fusion and juxtaposition conditions over left posterior (Fig. 2A) and right frontal (Fig. 2B) cortices. From 500 to 796 ms, there was a significant difference over left frontal-temporal cortex (Fig. 2C).

In order to localize the brain areas underlying these effects, inward continuations of the Laplacian-transformed topographies were computed, thereby estimating current source density at the cortical surface and suggesting relatively discrete, superficial foci of activity [1,7]. From 368 to 496 ms, this procedure indicated that the left posterior topographic focus (Fig. 2A) corresponded to a current source at left temporal-parietal cortex (Fig. 3A), with fused words exhibiting greater current density than juxtaposed words. The right frontal focus in Fig. 2B

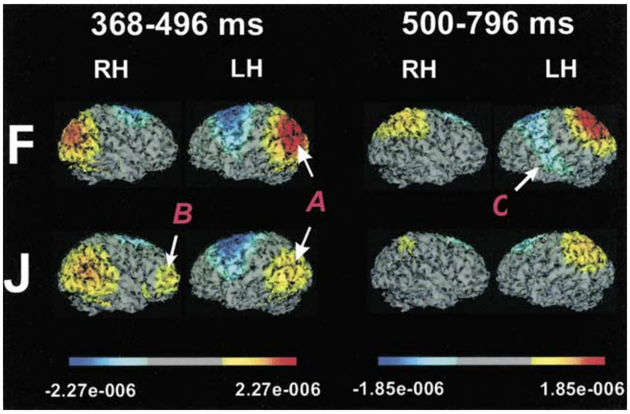

Fig. 3. Estimated current source densities at the cortical surface (current sources in red, sinks in blue). The upper and lower 33% of the scale is displayed. The left column shows sources and sinks plotted on the right and left hemisphere (RH, LH) for the 368–496 ms epoch; the right column shows sources and sinks for 500–796 ms. Arrows indicate foci of effects. The top row shows results for fused words, the bottom row for juxtaposed (the top two rows correspond to the maps shown in the top two rows of Fig. 2).

corresponded to a right anterior prefrontal current source, with juxtaposed words exhibiting greater current density (Fig. 3B). From 500 to 796 ms, the focus in Fig. 2C corresponded to a left frontal-temporal current sink, with fused words exhibiting greater negative current density (Fig. 3C).

Previous studies have yielded evidence of left temporal-parietal and right prefrontal involvement in episodic memory retrieval [4,11,19]. Left parietal activation has been inferred to reflect conscious recollective processes [4]. The present parietal activation is stronger for fused pairs than for juxtaposed pairs, consistent with the superior response accuracy and speed for fused pairs.

Neuroimaging studies have isolated separate right prefrontal activations during memory retrieval. Dorsolateral activation has been theorized to reflect a mechanism that monitors ongoing retrieval processes [11]. In our experiment, right prefrontal activity was stronger for juxtaposed than for fused pairs, consistent with the notion that the greater difficulty involved in retrieving juxtaposed pairs requires greater online monitoring and adjustment of retrieval. However, the present results yielded right prefrontal activity somewhat more anterior and ventral than the dorsolateral region implicated in retrieval monitoring. Instead, this current source may correspond to a right anterior ventral activation shown to be sensitive to retrieval success [11].

Left lateral frontal-temporal activity such as that observed from 500 to 796 ms for fused pairs has not typically been found in studies of episodic retrieval, though it does commonly occur in semantic tasks. Left inferior prefrontal activity in semantic memory tasks has been theorized to reflect a role in controlling complex semantic retrieval [3,9,17]. Left anterior temporal cortex has also been hypothesized to exert top-down control on semantic retrieval [14]. That such activity was observed for fused pairs is consistent with the notion that fusion-based associative retrieval involves conceptual mediation. Moreover, this left frontal-temporal activity occurred after the left parietal and right frontal activations typically seen in episodic memory experiments, even though behavioral responses on fusion trials were quicker than on juxtaposition trials. This further highlights the advantage to associative retrieval afforded by conceptual fusion during encoding.

These results demonstrate that retrieval of episodic associations formed by conceptual fusion involves processes different from those involved in retrieval of juxtaposition-based associations. Moreover, these results indicate that associative memory involves more than simple connections between ideas and more than holistic episodic conjunctions. Memory is generative in that a pair of concepts can be semantically fused to form a new concept that can mediate associative memory for the constituent items. Semantic fusion therefore supplements and reinforces other associative mechanisms, thereby enhancing retrieval.

Acknowledgements

This research was supported by grants from NIMH and NIDCD to J.K.

References

[1] F. Babiloni, C. Babiloni, F. Carducci, L. Fattorini, C. Anello, P. Onorati, A. Urbano, High resolution EEG: a new model-dependent spatial deblurring method using a realistically-shaped MR-constructed subject's head model, Electroenceph. clin. Neurophysiol. 102 (1997) 69–80.

[2] E.G. Boring, A History of Experimental Psychology, 2nd Edition., Appleton-Century-Crofts, New York, 1957.

[3] I.G. Dobbins, H. Foley, D.L. Schacter, A.D. Wagner, Executive control during episodic retrieval: multiple prefrontal processes subserve source memory, Neuron 35 (2002) 989–996.

[4] D.I. Donaldson, M.D. Rugg, Recognition memory for new associations: electrophysiological evidence for the role of recollection, Neuropsychologia 36 (1998) 377–395.

[5] H. Eichenbaum, M. Bunsey, On the binding of associations in memory: clues from studies on the role of the hippocampal region in paired associate learning, Curr. Dir. Psychol. Sci. 4 (1995) 19–23.

[6] C.L. Gagne, E.J. Shoben, Influence of thematic relations on the comprehension of modifier-noun combinations, J. Exp. Psychol. [Learn. Mem. Cogn.] 23 (1997) 71–87.

[7] A. Gevins, J. Le, H. Leong, L.K. McEvoy, M.E. Smith, Deblurring, J. Clin. Neurophys. 16 (1999) 204–213.

[8] A. Glenberg, What language needs from memory (and vice versa), in: H.L. Roediger, J.S. Nairne, I. Neath, A.M. Suprenant (Eds.), The Nature of Remembering: Essays in Honor of Robert C. Crowder, American Psychological Association, Washington, DC, 2001, pp. 351–368.

[9] B.T. Gold, R.L. Buckner, Common prefrontal regions coactivate with dissociable posterior regions during controlled semantic and phonological tasks, Neuron 35 (2002) 803–812.

[10] R. Greene, Similarity and associative recognition, J. Mem. Lang. 45 (2001) 573–584.

[11] R.N.A. Henson, M.D. Rugg, T. Shallice, R.J. Dolan, Confidence in recognition memory for words: dissociating right prefrontal roles in episodic retrieval, J. Cogn. Neurosci. 12 (2000) 913–923.

[12] M.J. Kahana, Associative symmetry and memory theory, Mem. Cogn. (2003) in press.

[13] J. Kounios, R.W. Smith, W. Yang, P. Bachman, M. D'Esposito, Cognitive association formation in human memory revealed by spatiotemporal brain imaging, Neuron 29 (2001) 297–306.

[14] A. Martin, L. Chao, Semantic memory and the brain: structure and processes, Curr. Opin. Neurobiol. 11 (2001) 194–201.

[15] G. McCarthy, C.C. Wood, Scalp distributions of event-related potentials: an ambiguity associated with analysis of variance models, Electroenceph. clin. Neurophysiol. 64 (1985) 203–208.

[16] T.H. Oostendorp, J. Delbeke, D.F. Stegeman, The conductivity of the human skull: results of *in vivo* and *in vitro* measurements, IEEE Trans. Biomed. Eng. 47 (2000) 1487–1492.

[17] A.D. Wagner, E.J. Pare-Blagoev, J. Clark, R.A. Poldrack, Recovering meaning: left prefrontal cortex guides controlled semantic retrieval, Neuron 31 (2001) 329–338.

[18] E.J. Wisniewski, When concepts combine, Psychon. Bull. Rev. 4 (1997) 167–183.

[19] A.P. Yonelinas, The nature of recollection and familiarity: a review of 30 years of research, J. Mem. Lang. 46 (2002) 441–517.