Research Report

MONITORING CONSCIOUS RECOLLECTION VIA THE ELECTRICAL ACTIVITY OF THE BRAIN

Ken A. Paller,[1] Marta Kutas,[2] and Heather K. McIsaac[3]

[1]*Department of Psychology, Northwestern University;* [2]*Department of Cognitive Science, University of California, San Diego; and* [3]*Department of Psychology, University of British Columbia*

Abstract—*Although another person's experience of recollection cannot be observed directly, we have found that the underlying operations can be monitored using noninvasive electrophysiological techniques. Results from two experiments showed that brain potentials elicited 500 to 900 ms after the onset of visually presented words vary systematically in amplitude with manipulations that influence the extent to which subjects engage in recollective processing. These brain potentials can thus be construed as correlates of the subjective experience of recollection.*

In *The Rediscovery of the Mind* (1992), philosopher John Searle accused cognitive scientists of skirting the very issue that ought to be at the core of investigation—consciousness. However, this criticism is at odds with a growing research trend aimed at rediscovering the mind in the neurophysiological operations of the brain. Here we report on experimental results that exemplify this trend in the field of memory research by empirically isolating an electrophysiological index of conscious recollection.

Noteworthy refinements in conceptualizing recollection have recently been derived from studies of patients with organic amnesia. These patients have impairments in conscious retrieval of recently learned facts or recently experienced events. But when memory is tested without reference to prior learning episodes, amnesic patients can show normal performance that belies their apparent inability to remember (Graf, Squire, & Mandler, 1984; Schacter, 1987; Shimamura, 1986; Warrington & Weiskrantz, 1968). In these so-called *implicit memory tests,* patients typically make faster and more accurate decisions about recently encountered stimuli than about other stimuli, an outcome termed *priming.* Dissociations between these different types of memory performance have been used to argue for multiple anatomically distinct memory systems in the brain (Squire, 1987; Tulving & Schacter, 1990). Yet there is still much to learn about the processes that converge to allow people to say, "I remember." For instance, there is an urgent need to be able to distinguish circumstances wherein recollection occurs from those wherein recollection does not occur. In this report, we demonstrate how measures of brain electrical activity called event-related potentials (ERPs) can be used to monitor recollection during an implicit memory test.

Systematic variation in recollection was achieved by intermingling two study tasks that differ in the extent to which word meaning must be accessed and that are known to produce a memory dissociation by leading to different levels of recollection but to similar levels of priming (Craik & Lockhart, 1972; Jacoby & Dallas, 1981). This dissociation was verified by obtaining measures of recognition memory as well as measures of priming in a lexical decision test, in which the response latency to discriminate words from nonwords is faster for studied words than for unstudied words. Although the lexical decision test is an implicit memory test, the presentation of a studied word in this test can provoke subjects to engage in recollection. Our experimental strategy rests on the assumption that such "incidental recollection" occurs and that it can be monitored electrophysiologically. ERPs were evaluated by comparing conditions that differed in terms of incidental recollection while other factors were held constant. Thus, the key analyses involved comparisons between ERPs elicited by words as they were presented during the lexical decision test, with separate ERPs computed for each study condition. Furthermore, these comparisons were made in two experiments that differed in the extent to which the response requirements in the test phase encouraged incidental recollection.

Address correspondence to Ken A. Paller, Department of Psychology, Northwestern University, 2029 Sheridan Rd., Evanston, IL 60208-2710; e-mail: kap@nwu.edu.

METHOD

Subjects were right-handed, native-English-speaking men and women, aged 19 to 25 years, who gave informed consent. There were 12 subjects in each experiment. Each subject was fitted with an elastic cap with embedded electrodes. Recordings were made from 13 scalp locations. In addition, two channels were used for monitoring horizontal and vertical eye movements; trials contaminated by electroocular artifacts were excluded from the analyses. The reference was the average response from the left and right mastoid, the bandpass was 0.01 to 100 Hz, the sampling rate was 250 Hz, and waveforms were low-pass filtered at 25 Hz for presentation purposes.

Each experiment included eight blocks, and a unique set of 30 words was presented in each block, first in a study phase and then in a test phase. Each word was presented within a rectangular frame. Subjects were given detailed instructions prior to the first block, and visual cues were shown to simplify the response requirements. Each decision was registered via a button-press.

The design of the study phase (Fig. 1a) was the same in the two experiments. For the *image task* (the semantic study condition), subjects formed an image of each word's referent and indicated whether it was smaller or larger than the video monitor on which the words were displayed. For the *syllable task* (the nonsemantic study condition), subjects indicated whether the word comprised only one or more than one syllable.

In the test phase of Experiment 1, subjects viewed a series of letter strings and indicated as quickly as possible

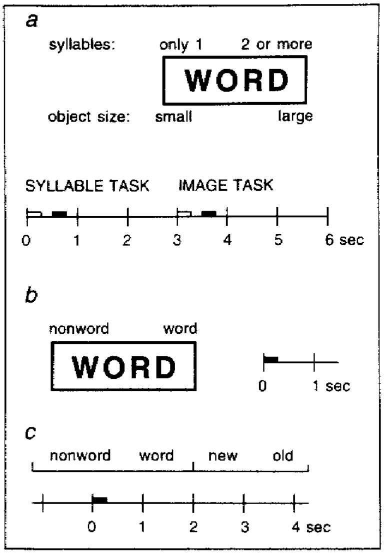

Fig. 1. Stimulation procedures. In the study phase for Experiments 1 and 2 (a), the display included cues above and below the rectangle to indicate which hand was to make which response (left hand for "only 1" or right hand for "2 or more" in the syllable task; left hand for "small" or right hand for "large" in the image task). Cues and words for one task were presented in green, whereas cues and words for the other task were presented in red. The time line shows the timing of stimulus presentation, with black bars corresponding to words (flashed for 300 ms) and white bars corresponding to cues (brightened for 300 ms). Tasks alternated word by word such that 15 words were presented in each task. In the test phase for Experiment 1 (b), a letter string was flashed for 300 ms every 1.5 s, as shown in the time line. Cues above the rectangle indicated that nonwords required a left-hand response and words required a right-hand response. The test phase included 30 words from the prior study phase, 15 new words, and 15 nonwords. In the test phase for Experiment 2 (c), cues for the lexical decision test were shown during the first part of each trial and replaced by cues for the recognition test (left hand for "new" or right hand for "old") during the second part of each trial, as indicated above the time line. As in Experiment 1, the test phase included 30 words from the prior study phase, 15 new words, and 15 nonwords, each flashed for 300 ms.

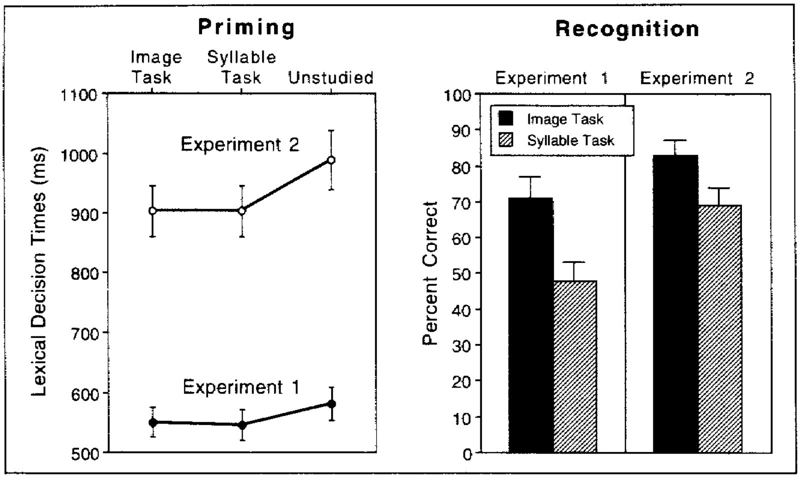

Fig. 2. Behavioral results from the lexical decision test (left) and the recognition test (right). The priming effect in lexical decision times was not affected by study task, whereas recognition performance was better for words from the image task than for words from the syllable task. Error bars indicate standard errors of the mean within condition.

whether each one was or was not an English word (Fig. 1b). Test items included equal proportions of (a) nonword letter strings that were orthographically and phonologically wordlike (e.g., *glone*, *drice*), (b) words from the image task, (c) words from the syllable task, and (d) words that had not appeared in the study phase. The specific words used in each of the latter three conditions were counterbalanced across subjects.

Response requirements during the test phase differed in Experiment 2. Whereas only lexical decisions were made in Experiment 1, both lexical decisions and recognition judgments were made in Experiment 2 (Fig. 1c). The added response requirement was intended to increase the likelihood that recollection would occur while subjects were performing the implicit memory test.

At the conclusion of each experiment, recognition was tested. Subjects were given a list of all 240 words from the two study tasks intermixed with 240 new words and asked to circle the words they remembered having studied.

RESULTS

Performance measures showed that recognition was influenced by study task whereas priming of lexical decisions was not. This memory dissociation was observed in both experiments, as shown in Figure 2.

In Experiment 1, recognition scores were clearly better for words from the image task than for words from the syllable task ($t[9] = 8.8$, $MS_e = 33$, $p < .0001$, data available for 10 subjects only). Lexical decisions were 33 ms faster for the studied words than for words not shown in the study phase ($t[11] = 7.7$, $MS_e = 115$, $p < .0001$). However, lexical decision times did not differ for words from the image task versus words from the syllable task ($t[11] = 1.5$, $MS_e = 57$).

In Experiment 2, recognition scores were also better for words from the image task than for words from the syllable task ($t[11] = 8.8$, $MS_e = 26$, $p < .0001$, data from test phase). Lexical decisions were 87 ms faster for studied than for unstudied words ($t[11] = 6.1$, $MS_e = 1{,}195$, $p < .0001$), but did not differ as a function of study task ($t[11] = 0.04$, $MS_e = 282$). As performance requirements in the test phase were considerably more demanding in Experiment 2 than in Experiment 1, overall lexical decision times were longer ($t[11] = 7.4$, $MS_e = 15{,}318$, $p < .0001$), and the magnitude of the priming effect was larger ($t[11] = 3.5$, $MS_e = 1{,}287$, $p < .005$).[1]

The behavioral results thus showed that memory tested explicitly via measures of recognition accuracy was influenced by the study-task manipulation, whereas memory tested implicitly via lexical decision times was not. Furthermore, a novel perspective on the nature and time course of these memory processes was provided by an examination of ERPs recorded during the test phase.

As can be seen in the upper portion of Figure 3, ERPs were more positive for studied than for unstudied words, starting approximately 300 ms after word onset. This effect of word repetition was clear in both experiments (see Table 1) and accords well with the literature (Kutas, 1988; Paller, 1993; Rugg, 1995). Unlike the previous experiments, which did not allow the separate contribution of recollective processes to be determined, in these studies we took advantage of the dissociative influence of the study-task manipulation to isolate an ERP effect specific to recollection. As shown in the lower portion of Figure 3, ERP amplitudes from 500 to 900 ms after word onset were larger for words from the image task than for words from the syllable task, although this difference was statistically significant only in Experiment 2 (see Table 1). Whereas we emphasize results from the Cz electrode, analogous results were apparent in recordings from other scalp locations (Paller, Kutas, & McIsaac, 1994).

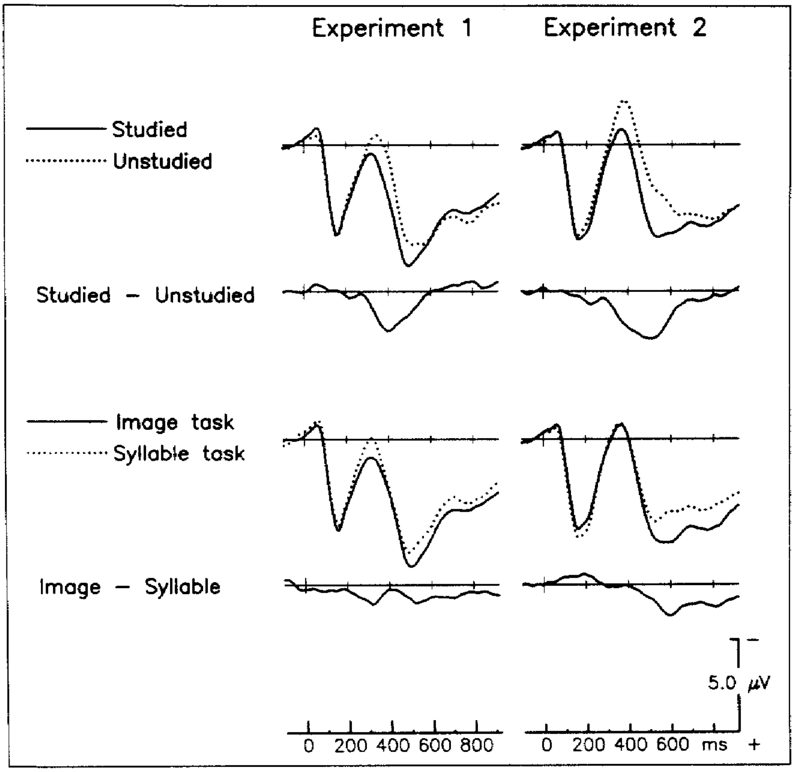

Fig. 3. Event-related potentials (ERPs) recorded during the test phase. Recordings shown are from the Cz electrode, located at the vertex of the scalp. The top two rows show that ERPs to studied words were more positive than ERPs to unstudied words, beginning at about 300 ms after word onset. The bottom two rows show that ERPs to words from the image task were more positive than ERPs to words from the syllable task. This difference was significant in Experiment 2 between 500 and 900 ms after word onset.

DISCUSSION

The key electrophysiological finding was that words from the two study tasks—which yielded equivalent priming as assessed by lexical decision times—elicited different ERPs during the lexical decision test. This ERP effect mirrored the study-task effect on recognition, and can thus be interpreted as an index of recollection, even though recollection was incidental (i.e., not necessary for performing the implicit memory test).

This pattern of electrophysiological results replicates that found previously using a different implicit memory test, a word identification test in which subjects attempted to identify words presented under tachistoscopic masking that made many of the words unidentifiable (Paller & Kutas, 1992). A priming effect was observed, in that words that had also been shown in the study phase were identified more often then were unstudied words. Further, words from a semantic study task and words from a nonsemantic study task led to similar levels of priming. In contrast, study task had a large effect on recollection as measured by free recall and recognition performance. Electrophysiological results showed that study task had a strong influence on ERPs elicited by words presented during the word identification test. Similarities between the study-task effect on test-phase ERPs found by Paller and Kutas (1992) and in the present experiment attest to the robustness and generalizability of the results and imply that the recollection effect is not contingent on the type of implicit memory test used.

An alternative procedure for recording ERPs during recollection was used by Smith (1993), who applied a modified recognition paradigm developed by Tulving (1985). In addition to making recognition judgments, subjects were

1. The finding that lexical decision times were prolonged in Experiment 2 relative to Experiment 1 has implications for other experiments in which dual response requirements have been used (e.g., Johnston, Dark, & Jacoby, 1985). Specifically, the manner in which subjects perform an implicit memory test can be dramatically changed by introducing the additional requirement of making a recognition decision on each trial. Additional performance requirements can alter the demand characteristics of memory tests, and measures of memory must be interpreted with this in mind.

Table 1. *Measurements of differences in event-related potentials (ERPs)*

Window (ms)	Experiment 1 Study effect	Experiment 1 Task effect	Experiment 2 Study effect	Experiment 2 Task effect
0–100	0.2	−0.1	−0.1	−0.2
100–200	−0.1	0.1	0.2	−0.4
200–300	0.2	0.5	0.6	−0.3
300–400	1.4 (4.1***)	0.6	1.2 (3.0*)	−0.1
400–500	1.7 (3.6***)	0.4	2.3 (4.9***)	0.4
500–600	1.4	0.8	2.3 (3.7***)	1.3 (3.1**)
600–700	−0.2	0.5	0.8	1.3 (3.4**)
700–800	−0.5	0.5	0.4	1.1 (3.0*)
800–900	−0.3	0.3	0.3	1.0 (2.5*)

Note. Values show mean amplitude measurements from the Cz electrode (in μV) computed as differences between conditions (study effect = ERP to studied words − ERP to unstudied words; task effect = ERP to words from the image task − ERP to words from the syllable task). Significant *t* values are shown in parentheses.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .005$.

asked to decide for each recognized item whether they experienced recollection or merely a sense of familiarity devoid of the contextual retrieval that is the hallmark of recollection. Electrophysiological findings corresponding to these two judgments did not appear to isolate qualitatively different ERP effects, and thus some doubt remains concerning the adequacy of this procedure for isolating an ERP correlate of recollection.

A subsequent study, however, was more successful at revealing an ERP effect that may be specific to recollection (Smith & Guster, 1993). Subjects discriminated memorized words from other words in either a "subspan" condition in which there was only 1 memorized word or a "supraspan" condition in which there were 10 memorized words. Smith and Guster (1993) argued that only the supraspan condition required retrieval from secondary memory and that an increased positivity from 500 to 650 ms in the supraspan versus subspan condition was thus associated with recollection, an interpretation that is consistent with our findings.

Another method that was recently used to associate an ERP effect with recollection was to require subjects to make source judgments (Wilding & Rugg, 1994). Each word presented in the study phase was heard in either a male or a female voice. In the test phase, subjects made a recognition judgment (old vs. new) for each word as well as a source judgment for words judged old (male vs. female voice in study phase). ERPs to new words differed from ERPs to old words only for the old words that were both recognized and attributed to the correct study condition. Demonstrated knowledge of the study context is arguably a good indication that the recognition judgment was made on the basis of recollection rather than merely on the basis of a feeling of familiarity.

In conclusion, the present results imply that ERPs reliably and systematically fluctuate with the likelihood that subjects experience recollection. The study-task manipulation showed that more meaningful encoding led to better recognition performance and to larger ERP amplitudes at retrieval. Similarly, the test-phase manipulation showed that conditions maximizing the probability of recollection during the implicit memory test led to larger ERP differences. ERP measures can thus provide real-time evidence about recollective processing.[2] The available evidence suggests that this association is not limited to incidental recollection but can also hold for recollection as it occurs during a recognition test. Despite the fact that subjects' reports based on their introspections are notoriously unreliable, our results show that subjective experience can be brought into the realm of empirical investigation by monitoring electrical activity that is coincident with the experience of recollection.

2. One way in which the present approach may be especially useful is in conjunction with neuroimaging techniques that have lower temporal resolution but higher spatial resolution. For example, studies of memory functions using positron emission tomography have associated blood flow changes in frontal lobe regions with recollection, but measures were obtained by averaging over periods of 40 s or more (Buckner et al., 1995; Grasby et al., 1993; Squire et al., 1992; Tulving et al., 1994).

Acknowledgments—We thank R. Ohst and N. Herold for technical and programming assistance, and M. Besson, C. Brown, M. Grabowecky, P. Hagoort, F. Haist, P. Holcomb, R. Kluender, and L. Squire for comments on previous versions of the manuscript. Preliminary results were presented at the 34th annual meeting of the Psychonomic Society, Washington, D.C., November 1993, and at the inaugural meeting of the Cognitive Neuroscience Society, San Francisco, March 1994. This research was supported by grants to M. Kutas from the National Institute of Child Health and Human Development and from the National Institute on Aging.

REFERENCES

Buckner, R.L., Petersen, S.E., Ojemann, J.G., Miezin, F.M., Squire, L.R., & Raichle, M.E. (1995). Functional anatomical studies of explicit and implicit memory retrieval tasks. *Journal of Neuroscience, 15*, 12–29.

Craik, F.I.M., & Lockhart, R.S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11*, 671–684.

Graf, P., Squire, L.R., & Mandler, G. (1984). The information that amnesic patients do not forget. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 164–178.

Grasby, P.M., Frith, C.D., Friston, K.J., Bench, C., Frackowiak, R.S.J., & Dolan, R.J. (1993). Functional mapping of brain areas implicated in auditory-verbal memory function. *Brain, 116*, 1–20.

Jacoby, L.L., & Dallas, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 110*, 306–340.

Johnston, W.A., Dark, V.J., & Jacoby, L.L. (1985). Perceptual fluency and recognition judgments. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11*, 3–11.

Kutas, M. (1988). Review of event-related potential studies of memory. In M.S. Gazzaniga (Ed.), *Perspectives in memory research* (pp. 181–218). Cambridge, MA: MIT Press.

Paller, K.A. (1993). Elektrophysiologische Studien zum Menschlichen Gedächtnis [Electrophysiological studies of human memory]. *Zeitschrift für EEG und EMG, 24*, 24–33.

Paller, K.A., & Kutas, M. (1992). Brain potentials during memory retrieval provide neurophysiological support for the distinction between conscious recollection and priming. *Journal of Cognitive Neuroscience, 4*, 376–391.

Paller, K.A., Kutas, M., & McIsaac, H.K. (1994). *An electrophysiological measure of priming of visual word form.* Unpublished manuscript, Northwestern University, Evanston, IL.
Rugg, M.D. (1995). Event-related potential studies of human memory. In M.S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 789–801). Cambridge, MA: MIT Press.
Schacter, D.L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 501–518.
Searle, J.R. (1992). *The rediscovery of the mind.* Cambridge, MA: MIT Press.
Shimamura, A.P. (1986). Priming effects in amnesia: Evidence for a dissociable memory function. *Quarterly Journal of Experimental Psychology, 38A,* 619–644.
Smith, M.E. (1993). Neurophysiological manifestations of recollective experience during recognition memory judgments. *Journal of Cognitive Neuroscience, 5,* 1–13.
Smith, M.E., & Guster, K. (1993). Decomposition of recognition memory event-related potentials yields target, repetition, and retrieval effects. *Electroencephalography and Clinical Neurophysiology, 86,* 335–343.
Squire, L.R. (1987). *Memory and brain.* New York: Oxford University Press.
Squire, L.R., Ojemann, J.G., Miezin, F.M., Petersen, S.E., Videen, T.O., & Raichle, M.E. (1992). Activation of the hippocampus in normal humans: A functional anatomical study of memory. *Proceedings of the National Academy of Sciences, USA, 89,* 1837–1841.
Tulving, E. (1985). Memory and consciousness. *Canadian Psychologist, 26,* 1–12.
Tulving, E., Kapur, S., Markowitsch, H.J., Craik, F.I.M., Habib, R., & Houle, S. (1994). Neuroanatomical correlates of retrieval in episodic memory: Auditory sentence recognition. *Proceedings of the National Academy of Sciences, USA, 91,* 2012–2015.
Tulving, E., & Schacter, D.L. (1990). Priming and human memory systems. *Science, 247,* 301–306.
Warrington, E.K., & Weiskrantz, L. (1968). A new method of testing long-term retention with special reference to amnesic patients. *Nature, 217,* 972–974.
Wilding, E.L., & Rugg, M.D. (1994, March). *Electrophysiological correlates of recollection.* Paper presented at the inaugural meeting of the Cognitive Neuroscience Society, San Francisco.

(RECEIVED 4/22/94; ACCEPTED 7/4/94)

Forthcoming Papers

General Articles

Microgenetic Study of Change: What Has It Told Us?
Deanna Kuhn

Reflections on Affirmative Action Goals in Psychology Admissions
James Amirkhan, Hector Betancourt, Sandra Graham, Steven Regeser López, and Bernard Weiner

Feature Review

Strong Medicine: A Review of *House of Cards: Psychology and Psychotherapy Built on Myth,* by Robyn M. Dawes
Gregory A. Miller

Research Articles

Cognitive Profiles of Reading-Disabled Children: Comparison of Language Skills in Phonology, Morphology, and Syntax
D. Shankweiler, S. Crain, L. Katz, A.E. Fowler, A.M. Liberman, S.A. Brady, R. Thornton, E. Lundquist, L. Dreyer, J.M. Fletcher, K.K. Stuebing, S.E. Shaywitz, and B.A. Shaywitz

Right-Hemisphere Memory Superiority: Studies of a Split-Brain Patient
Janet Metcalfe, Margaret Funnell, and Michael S. Gazzaniga

Reading Skill and Suppression Revisited
Morton Ann Gernsbacher and Rachel R.W. Robertson

Response Style and Cross-Cultural Comparisons of Rating Scales Among East Asian and North American Students
Chuansheng Chen, Shin-ying Lee, and Harold W. Stevenson

Orthographic Representation and Phonemic Segmentation in Skilled Readers: A Cross-Language Comparison
Ilana Ben-Dror, Ram Frost, and Shlomo Bentin

Grouping by Proximity and Multistability in Dot Lattices: A Quantitative Gestalt Theory
Michael Kubovy and Johan Wagemans

Semantic Networks in the Divided Cerebral Hemispheres
Alice Cronin-Golomb

Research Reports

Perceived Continuity of Occluded Visual Objects
Steven Yantis