

The covert interplay between perception and memory: event-related potential evidence

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Abstract

Neurocognitive models of visual object identification have focussed on processes at the moment of identification, when perceivers can actually name what they see. Less well known is the timecourse of processes *preceding* and *leading to* actual identification. To track neuromental processes involved in visual identification, behavioral measures and event-related potentials (ERPs) were recorded in two experiments prior to, during and after the identification of fragmented objects, half of which had been shown in their complete versions in a previous study phase. Each object was revealed in a sequence of frames wherein the object was represented by an increasingly less and less fragmented image up to the complete version. A shift in ERPs, around 300 ms and beyond, from negativity to positivity, marked the transition from non-identification to identification. However, while for new stimuli such a shift appeared abruptly from non-identification to identification, for recently-studied objects a late positive wave emerged in response to unidentified fragments at a level just prior to overt identification. Thus, ERPs reflected covert processes associated with a successful match between the current visual information and episodic recently-stored memory traces, which predicted overt identification. © 1998 Elsevier Science Ireland Ltd. All rights reserved

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1. Introduction

Visual object identification entails a number of different and complex processes occurring in parallel in multiple levels of the visual hierarchy (Ungerleider, 1995; Sereno et al., 1996). Perceiving a visual stimulus as ‘something namable’ requires not only the analysis of the physical input but also some contact (whether via comparison, search, or constraint-satisfaction) among the neural representations of the stimulus (including both single features and higher-order relations among them) with memories that perceivers have amassed through a lifetime of experience with objects. Some of these processes are covert and take place prior to any overt behavior on the part of the observer (Farah, 1990; Kosslyn and Koenig, 1992; Bruce et al., 1996). To investigate the interaction of visual information and memory in the identification process, fragmen-

ted objects have been widely used in the literature (Leeper, 1935; Snodgrass and Feenan, 1990; Stuss et al., 1992).

To track the timecourse of covert and overt processes leading to identification, measures of behavior (accuracy and reaction time) were combined with measures of electrical brain activity (event-related potentials or ERPs) in two experiments during the successive presentation (and identification) of more and more fragments of objects, some of which had recently been studied (old) and some of which had not (new). ERPs to each visual stimulus were monitored from the moment the fragmented stimulus was presented until it was overtly identified. Specifically, our aim was to examine how and when the processing of varying amounts of visual input (number of fragments) was affected by different types of visual memory (episodic visual memory built up from a recent exposure vs. visual representations in semantic memory built up from years of exposure to the environment). The ERP was especially useful to this end because it allows the analysis of brain responses not only to the fragments that were successfully identified, but also to

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those that were not overtly identified. Thus, covert processes involved in the interplay between visual input and memory, which were not revealed by behavioral measures, could be investigated via ERP recordings. In order to verify the extent to which the main results obtained in Experiment 1 depended on the level of subjects' certainty in identifying the objects, subjects' degree of confidence was investigated in Experiment 2.

2. Method

2.1. Subjects

Having given written informed consent, 17 adults (9 women), between 19 and 30 years of age, participated in Experiment 1. Eighteen adults (8 women), between 19 and 30 years of age, participated in Experiment 2. All participants had normal or corrected-to-normal vision and were right-handed.

2.2. Stimuli

One hundred and fifty line-drawings of common objects spanning a number of categories (e.g. animals, clothes, vehicles, tools) were used (from the series by Snodgrass et al., 1987). Each drawing was presented on a CRT under the control of a personal computer. Each stimulus subtended between 5° and 10° of visual angle along both vertical and horizontal dimensions.

2.3. Electrophysiological recording

The electroencephalogram was recorded via tin electrodes embedded in an elastic cap from 19 scalp locations of the international 10–20 system (Jasper, 1958) including frontal (Fz, Fp1, Fp2, F2, F3, F7, F8), central (Cz, C3, C4), parietal (Pz, P3, P4), temporal (T3, T4, T5, T6) and

occipital (O1, O2) sites. An electrode over the left mastoid process served as a reference during recording; the data were re-referenced off-line to the average of the voltage activity at the left and right mastoids. Recordings between electrodes placed lateral to each eye were used to monitor horizontal eye movements, and an electrode below the right eye was used to monitor vertical eye movements and blinks. These potentials were used to eliminate artifactually-contaminated trials (roughly 10%). The electrical activity was amplified with a bandpass of 0.01–100 Hz and digitized at 250 Hz. ERPs were computed for epochs extending from 200 ms before to 1600 ms after image onset. Mean amplitude measurements were taken within designated latency ranges (300–600, 600–1000, 1000–1300, 1300–1600 ms) relative to the average amplitude in the 200 ms prior to each stimulus, in some cases base-to-peak amplitudes were also measured. All measurements were submitted to repeated-measures analyses of variance. The Greenhouse-Geisser correction for violations of sphericity was applied to all treatments with more than one degree of freedom in the numerator. The Tukey procedure was used for all post-hoc comparisons.

2.4. Procedure

Participants were tested individually in an electrically-isolated and sound-attenuating chamber. In the study phase of Experiment 1, 75 line drawings of 'complete' objects (fragmentation level 8) were flashed for 700 ms each. Approximately 1300–1800 ms before each object, the word 'name' or 'draw' appeared on the screen, informing participants of their task for the next object, 38 objects were named and 37 drawn. During the subsequent identification phase, all 75 objects from the study phase were intermingled with 38 new objects and presented randomly, one at a time, for identification. Each object was presented at 6 fragmentation levels (2,3,4,5,6 and 8) in an ascending sequence of frames from the most fragmented (level 2) to

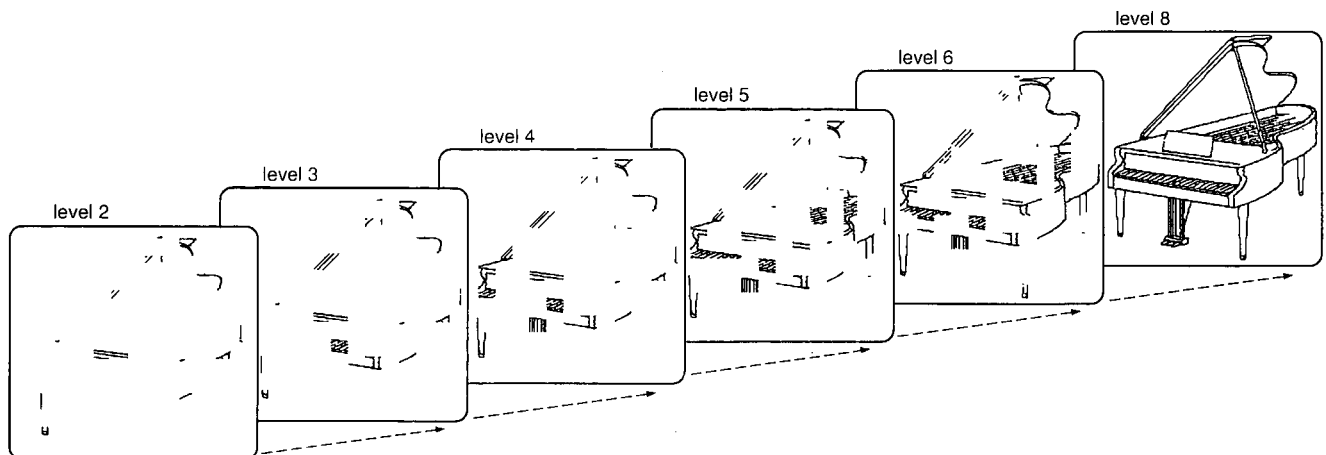


Fig. 1. An example of the ascending sequence of 6 levels of fragmentation for a 'piano' as presented during the identification phase. RTs and ERPs were analyzed relative to the fragmentation level at which identification (ID) occurred. If, for example, this object was identified at level 5 (ID), then two levels before (2b) refers to fragmentation level 3 and one level before (1b) refers to fragmentation level 4.

the least fragmented, i.e. complete, version (level 8) (Fig. 1). Every object was shown at all 6 fragmentation levels (for 500 ms each), regardless of the level at which it was actually identified. Participants were asked to press two buttons, one if they identified the objects and the other if they did not. The same procedure was used in Experiment 2, with the following exceptions: (1) in the study phase all the objects were drawn, (2) in the identification phase each object was presented at 7 levels of fragmentation (fragmentation level 7 was added). At each level, individuals pressed one of two buttons to indicate whether or not they could identify the object; two presses on the same button indicated high response certainty ('no-no' or 'yes-yes') whereas one press indicated a simple 'yes' or 'no'. Following a 'yes' or a 'yes-yes' response, participants were asked to name the object and were given feedback as to the correctness of their identification.

Given this design, the accuracy and speed of identification (and non-identification) of any given object could be a function of different memory traces (a specific episode for studied drawings vs. at best a generic image against which to compare new pictures), different types of encoding and processing (naming vs. drawing for old pictures), and information quality (levels of fragmentation for both old and new pictures).

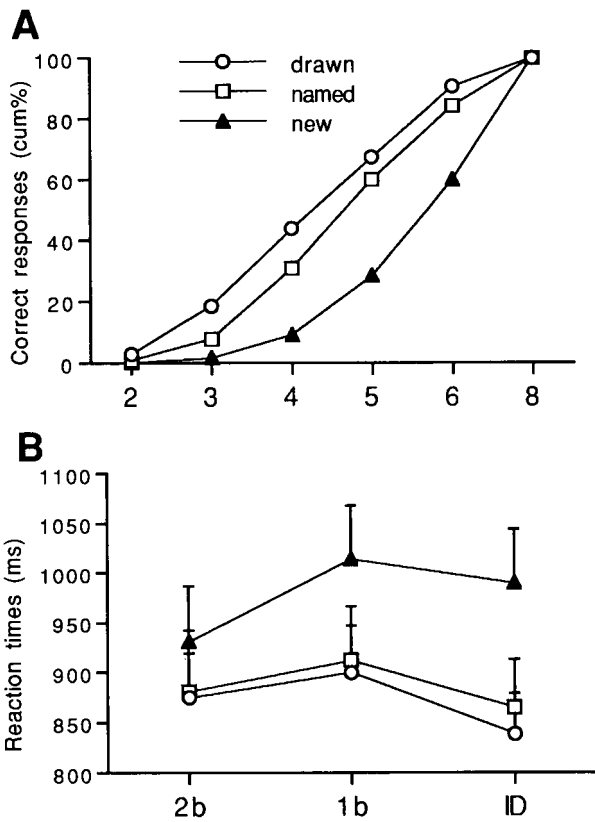


Fig. 2. (A) Mean cumulative percentage of correct identifications at each level of fragmentation for old (drawn and named) and new objects. (B) RTs were recorded at two levels before (2b), one level before (1b) and identification moment (ID) for old (drawn and named) and new objects.

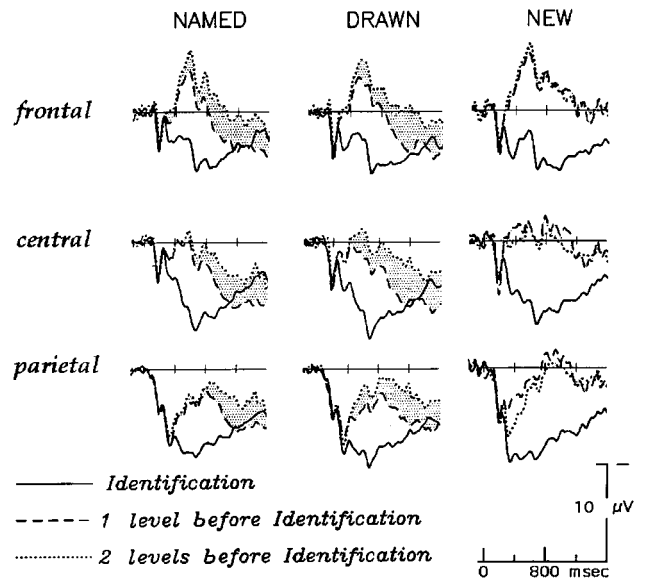


Fig. 3. Overlapped are grand average ERPs recorded from midline frontal, central and parietal recording sites to fragmented objects at the moment of identification (solid line), at 1-fragment level before ID (dashed line) and at 2-fragment level before ID (dotted line). This comparison is shown separately for the objects that had previously been named (left column), drawn (middle column), or were new (right column). Waveforms are plotted negative-up in this and all subsequent figures.

3. Results

3.1. Experiment 1

As the number of available fragments increased, identification performance improved for all objects. Fewer fragments were needed to identify previously-studied objects than new ones ($P < 0.00001$); and fewer fragments were needed to identify drawn than named objects, ($P < 0.01$) (Fig. 2A). Previous exposure also speeded not just 'yes-response' times at identification ($P < 0.001$) but also 'no-response' times at the fragmentation level immediately before identification ($P < 0.0001$), (Fig. 2B), suggesting that adding explicit memories to incoming stimuli speeded their perception more than adding generic memories. However, no significant reaction time (RT) change was found to mark the actual transition from unsuccessful to successful identifications. Thus, the only unequivocal overt sign that perceivers had achieved identification was that they correctly named the object. By contrast, a very large, late positive ERP component beginning around 300 ms and peaking at 700–800 ms signaled successful overt identification. This effect was evident at all recording leads (the following statistical data included recordings from all electrodes). The transition was manifest in a shift from a late negativity to a positivity in the ERPs, going from unidentified to identified fragments for both old (drawn and named) and new objects ($P < 0.0001$ for all windows from 300 to 1300 ms, and $P < 0.01$ for the window 1300–1600 ms). The critical comparison was between ERPs to unidentified fragmented objects

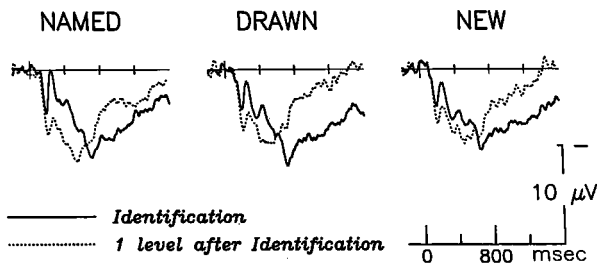


Fig. 4. Overlapped are grand average ERPs from the midline central site (Cz) to fragmented objects in the Name, Draw, and New conditions at the moment of identification (solid line) and at the immediately following level (dotted line).

(2-levels before identification), which were later identified but only after a substantial increase in the number of fragments and ERPs to unidentified fragmented objects (1-level before identification), which were identified with the addition of only a few more fragments. ERPs at 1-level before were more positive than those at 2-levels before identification for old (drawn and named), but not for new objects ($P < 0.05$). As shown in Fig. 3, at 2-levels before identification, ERPs to both old and new objects were characterized by a large, late negative wave. However, at the level just prior to the identification (1-level before), ERPs to new objects continued to show a large negativity whereas, surprisingly, ERPs to old objects showed a late negativity foreshortened by a smaller and later version of the positivity marking overt identification. This late positivity preceded the non-identification RTs for these fragments by about 200 ms. At the moment of actual identification there were no differences between ERPs to fragments of old and new objects (Fig. 3). After identification, the late positivity had a sharper slope of onset, an earlier peak, and a shorter duration than at identification ($P < 0.00001$) (Fig. 4).

3.2. Experiment 2

The extent to which the different patterns of ERPs for old and new objects at 1-level before identification could be due to variation in participants' response certainty was examined in a second experiment. Thus, participants were asked to indicate the certainty of their decision by pressing the 'yes' or 'no' button either once if they were certain or twice if they were very certain that they could or could not identify the object, respectively. The main findings from the first experiment were replicated: an abrupt shift from negativity to positivity for new objects and a gradual shift for old ones ($P < 0.05$) (Fig. 5). In addition, the pattern of ERPs to unidentified objects with response certainty held constant was examined and a relationship between previous exposure, response certainty and the presence of the late positivity in the ERP in response to the fragmentation level just before identification was found. For new objects no significant difference was found between 2-levels and 1-level before for either 'no' or 'no-no' responses, while for drawn objects the 2-levels before versus the 1-level

before was more positive for 'no' than for 'no-no' responses ($P < 0.01$). The late positivity, present particularly for studied objects, associated with a less certain response ('no'), suggests that the response system can tap into the identification decision of which the person was not yet fully aware (Fig. 5). Response certainty also interacted with previous exposure at identification: ERPs were generally more positive for decisions rendered with higher ('yes-yes') than lower ('yes') certainty (Wilkinson and Seales, 1978) from 300 to 1600 ms (e.g. 600–1000 ms, $P < 0.025$). In the same window there was also a significant study by response-certainty interaction ($P < 0.025$) indicating that the effect was quite large for new objects and unremarkable for studied objects (Fig. 6).

4. Discussion

The identification of visual input as a namable object requires a finite amount of time, albeit less time the better the quality of the input and the more recent and concrete the memories which supported its visual analysis. While this dynamic interplay between the visual input and of the memory was only partially apparent in overt behavior (e.g. greater accuracy and speed for old objects) and was in large part not available to conscious recollection, it was reflected in the brain's electrical activity. Upon initial exposure to some object, as in Fig. 1, its identification is contingent on matches between the specific sensory representation(s) of this input and some prototypic or abstract representation of 'piano' built from years of experience with pianos (whether the prototype was a stored average or one computed online from existing token representations). After the initial exposure, however, identification

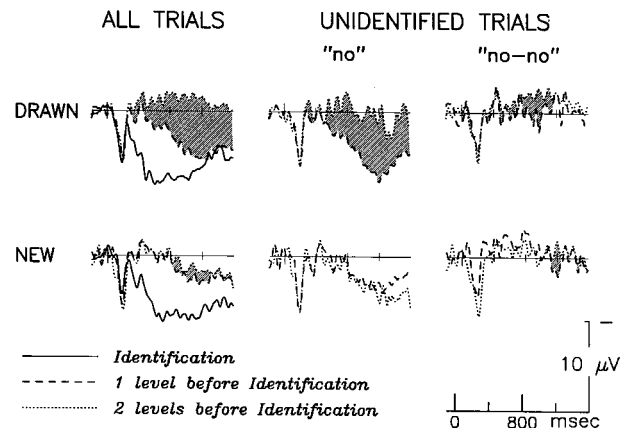


Fig. 5. Grand average ERPs from midline parietal (Pz) site for drawn and new objects in Experiment 2. In the left column, ERPs are overlapped for fragments at the moment of identification (solid line), 1-level before ID (dashed line), and 2-levels before ID (dotted line) regardless of response certainty. In the middle and right-hand columns, the ERPs to unidentified objects (i.e. the same data as in levels 1 and 2 before ID in the left-hand column) are shown separately for the 'no' and 'no-no' responses; overlapped are the ERPs to 1-level versus 2-levels before ID.

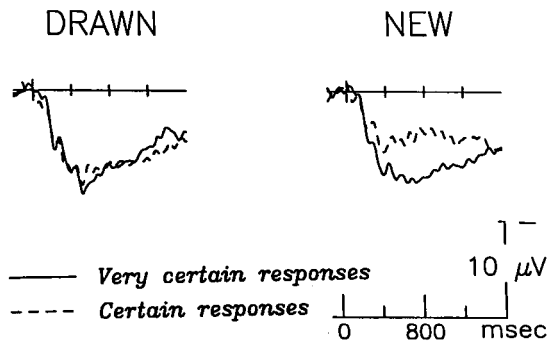


Fig. 6. Grand average ERPs from a midline site comparing certain ('yes') with very certain ('yes-yes') responses at the moment of identification for drawn and new objects in Experiment 2.

processes could also utilize (at least for a short while), newly-formed partial or whole representations of the particular object (i.e. token) just experienced (Treisman, 1992; Knowlton and Squire, 1993; Ishai and Sagi, 1995). Indeed, one beneficial consequence of drawing or naming objects shown in their entirety was the creation of such memory traces (tokens) to which the sensory representations of the fragmented visual input pattern could later be anchored. The late positivity in the ERP to fragments of previously-studied objects just prior to their identification reflected some aspect of this 'search and match' operation of the input with recent episodic traces. Consistent with what is known from the literature on the identification of fragmented stimuli (Snodgrass and Feenan, 1990; Roediger and McDermott, 1993; Snodgrass and Hirschman, 1994; Zhang et al., 1997), these memory traces appeared to prime the overt identification of recently-studied fragmented objects. However our ERP (and behavioral) results show that the priming effects are not restricted to the moment of overt identification, influencing processing prior to identification as well.

In conclusion, visual awareness associated with overt, conscious identification was preceded by unconscious brain activity that reflected settling into the best perceptual solution, which was made all the more attractive when it triggered a clear memory, even if it was not consciously recollected. The present data show that not only are we unaware of the early stages of basic visual processing in V1, as suggested by Crick and Koch (1995), but also of much higher-order processing further in the visual hierarchy. ERP recordings revealed the covert identification that anticipated the subsequent overt identification of objects for which episodic memory traces were recently stored and acted as primes. A dissociation between covert electrophysiological and overt behavioral data, similarly to what has been shown in amnesics (Lalouschek et al., 1997), might be found in brain-injured patients who show by their actions that they know what the object is and what it is typically used for but cannot name it. In these amnesic patients, ERPs might signal the identification in the absence of naming ability.

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References

- Bruce, V., Green, P.R. and Georgeson, M.A. *Visual Perception: Physiology, Psychology, and Ecology*. Psychology Press, Hove, 1996.
- Crick, F. and Koch, C. Are we aware of neural activity in primary visual cortex?. *Nature*, 1995, 375: 121–123.
- Farah, M. *Visual Agnosia: Disorders of Object Recognition and What They Tell Us About Normal Vision*. MIT Press, Cambridge, MA, 1990.
- Ishai, A. and Sagi, D. Common mechanisms of visual imagery and perception. *Science*, 1995, 268: 1772–1774.
- Jasper, H.H. The ten-twenty electrode system of the International Federation. *Electroenceph. clin. Neurophysiol.*, 1958, 10: 371–375.
- Knowlton, B.J. and Squire, L.R. The learning of categories: parallel brain systems for item memory and category knowledge. *Science*, 1993, 262: 1747–1749.
- Kosslyn, S.M. and Koenig, O. *Wet Mind. The New Cognitive Neuroscience*. Free Press, New York, NY, 1992.
- Lalouschek, W., Goldenberg, A., Marterer, R., Beisteiner, R., Lindinger, G. and Lang, W. Brain/behaviour dissociation on old/new distinction in a patient with amnesic syndrome. *Electroenceph. clin. Neurophysiol.*, 1997, 10: 371–375.
- Leeper, R. A study of a neglected portion of the field of learning – the development of sensory organization. *J. Genetic Psychol.*, 1935, 46: 41–75.
- Roediger, H.L., III, and McDermott, K.B. Implicit memory in normal human subjects. In H. Spinnler and F. Boller (Eds.), *Handbook of Neuropsychology* (Vol. 8). Elsevier, Amsterdam, 1993, pp. 63–131.
- Sereno, M.I., Dale, A.M., Reppas, J.B., Kwong, K.K., Belliveau, J.W., Brady, T.J., Rosen, B.R. and Tootell, R.B. Borders of multiple visual areas in humans revealed by functional magnetic resonance imaging. *Science*, 1996, 273: 889–893.
- Snodgrass, J.G. and Feenan, K. Priming effects in picture fragment completion: support for the perceptual closure hypothesis. *J. Exp. Psychol.: Gen.*, 1990, 119: 276–296.
- Snodgrass, J.G., Smith, B., Feenan, K. and Corwin, J. Fragmenting pictures on the Apple Macintosh computer for experimental and clinical applications. *Behav. Res. Meth. Instr. Comput.*, 1987, 19: 270–274.
- Snodgrass J.G. and Hirschman, E. Dissociation among implicit and explicit memory tasks: the role of stimulus similarity. *J. Exp. Psychol.: Learn. Mem. Cog.*, 1994, 20: 150–160.
- Stuss, D.T., Picton, T.W., Cherry, A.M., Leech, E.E. and Stethem, L. Perceptual closure and object identification: electrophysiological responses to incomplete pictures. *Brain Cogn.*, 1992, 19: 253–266.
- Treisman, A. Perceiving and re-perceiving objects. *Amer. Psychologist*, 1992, 47: 862–875.
- Ungerleider, L.G. Functional brain imaging studies of cortical mechanisms for memory. *Science*, 1995, 270: 769–775.
- Wilkinson, R.T. and Seales, D.M. EEG event-related potentials and detection. *Biol. Psychol.*, 1978, 7: 13–28.
- Zhang, X.L., Begleiter, H., Porjesz, B. and Litke, A. Visual object priming differs from visual word priming: an ERP study. *Electroenceph. clin. Neurophysiol.*, 1997, 102: 200–215.