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Event-Related Potentials and Recognition Memory For Pictures and Words: The Effects of Intentional and Incidental Learning

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ABSTRACT

Event-related potentials were recorded under conditions of intentional or incidental learning of pictures and words, and during the subsequent recognition memory test for these stimuli. Intentionally learned pictures were remembered better than incidentally learned pictures and intentionally learned words, which, in turn, were remembered better than incidentally learned words. In comparison to pictures that were ignored, the pictures that were attended were characterized by greater positive amplitude frontally at 250 ms and centro-parietally at 350 ms and by greater negativity at 450 ms at parietal and occipital sites. There were no effects of attention on the waveforms elicited by words. These results support the view that processing becomes automatic for words, whereas the processing of pictures involves additional effort or allocation of attentional resources. The N450 amplitude was greater for words than for pictures during both acquisition (intentional items) and recognition phases (hit and correct rejection categories for intentional items, hit category for incidental items). Because pictures are better remembered than words, the greater late positive wave (600 ms) elicited by the pictures than the words during the acquisition phase is also consistent with the association between P300 and better memory that has been reported.

DESCRIPTORS: Recognition memory, Event-related potentials.

There has been growing interest and progress in the application of psychophysiological models and methods to problems of cognitive psychology (Öhman, 1979; Donchin, Ritter, & McCallum, 1979). The present enquiry follows this direction by investigating an established memory phenomenon, the picture superiority effect, using visual event-related potentials (ERPs). The primary objectives of this research were to assess some current views on the processing of pictures and words using ERP methods and to examine ERP waves that develop during the process of memorizing these meaningful stimuli. To this end, ERP waveforms to pictures and words were recorded during the performance of a recognition memory task under conditions of intentional and incidental learning.

The superior memory for pictures to that for words is a robust phenomenon which has been demonstrated in several memory paradigms (Postman, 1978; Sperber, McCauley, Ragain, & Weil, 1979; Standing, Conezio, & Haber, 1970); it provides a useful framework for exploring the mechanisms that are thought to support memory function. Memory for pictorial stimuli is extremely accurate, durable, and extensive compared to that for verbal stimuli (Kroll & Potter, 1984; Postman, 1978; Sperber et al., 1979). Although it is widely acknowledged that the complexity and distinctiveness of pictures contribute substantially to the picture superiority effect (Anderson, 1978), pictures are remembered with greater accuracy even when pictures and their verbal labels are matched on size, colour, spatial distribution, and detail of information (Nelson, Metzler, & Reed, 1974). Thus, al-

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though the strength of the picture superiority effect is impressive, it is not yet fully understood.

At present, there is some evidence that pictures and words differ, at an early stage of stimulus processing, in the type of information that is assimilated. For pictures, it has been shown that physical features are integrated over individual visual fixations (Jolicoeur, Gluck, & Kosslyn, 1984), whereas the information obtained from a single fixation for words is abstract and relatively independent of physical form (Rayner, McConkie, & Zola, 1980). Whether these early processing differences contribute to the picture superiority effect is not known. There is also evidence suggesting that pictures and words differ in later stages of processing. Lexical and phonological access may be automatic for words but not for pictures (Henderson, 1982; Schneider & Shiffrin, 1977; Coltheart, 1978). For example, it takes longer to name a picture than to read the verbal label of the picture (Potter & Faulconer, 1975). This suggests that picture naming may require more effortful processing, or access of additional semantic information, prior to lexical or phonological encoding (Nelson, Reed, & McEvoy, 1977). According to this view, the automatic processing of words develops through practice and is performed without the necessity or benefit of intention. That is, automatic processing is conceived as a facilitative process that requires minimal allocation of attentional resources (cf. Hasher & Zacks, 1979). In contrast, it is thought that the processing of pictures typically requires additional allocation of attentional resources or effort, and benefits from this intention, for example, with greater memorability.

In the present study, an incidental learning paradigm is used to examine within-stimulus changes in memory accuracy and the concomitant effects on the ERP waves to pictures and words. The effects of incidental and intentional learning are important criteria for distinguishing automatic from effortful processing (cf. Hasher & Zacks, 1979). In general, effects that are attributed to automatic processing would be evident during both intentional and incidental conditions, whereas effects that are influenced by effortful processing would be attenuated during incidental conditions. Given that automatic processes, by definition, require minimal attentional resources, they should occur equally under intentional and incidental learning conditions. In contrast, effortful processing, which requires the allocation of attentional capacity, should occur only under intentional learning. During acquisition, the differences between intentional and incidental learning might provide some insight into the ERP waves that are associated with the automatic or effortful encoding into memory for each stimulus type. During the recognition memory test, the comparison of the items presented in the incidental condition with those items in the intentional condition will enable an assessment of ERP waves that are associated with difficulty of retrieval or memory search activity. It is assumed that target items from the incidental learning condition, where effortful, controlled, or associative processing is discouraged, are more difficult to retrieve than items from the intentional learning condition.

An analysis of picture and word ERP waveforms obtained during a recognition memory task can also provide useful independent evidence of picture and word processing that is relevant to the picture superiority memory effect. Several studies have implicated a parieto-central positive wave, P300, in memory processing. This P300 wave is sensitive to features that are thought to be important determinants of the picture superiority effect, notably stimulus complexity, information content, and stimulus novelty (cf. Johnson, 1986). In paradigms that involve more complex decisions such as memory tasks, the P300 exhibits peak amplitude in the 500–600 ms range (e.g., Karis, Fabiani, & Donchin, 1984).

A direct relationship between P300 amplitude and memory was proposed from theoretical considerations by Donchin (1981) and his colleagues; they argue that the events that elicit a P300 require the updating or revision of working memory. This view is somewhat similar to that proposed in models of the orienting response (Sokolov, 1963; Öhman, 1979). It has been shown that during the acquisition phase of a recognition memory task, words that were subsequently recognized elicited late positive waves with shorter latencies than unrecognized words, but no amplitude differences were observed (Johnson, Pfefferbaum, & Kopell, 1985). However, an enhanced amplitude late positive wave was associated with better memory for verbal items in several recent reports (Karis et al., 1984; Fabiani, Karis, & Donchin, 1986; Neville, Kutas, Chesney, & Schmidt, 1986; Paller, Kutas, & Mayes, 1987; Paller, McCarthy, & Wood, in press). It is also notable that orienting response magnitude predicts the memorability of pictures and words (Stelmack, Plouffe, & Winogron, 1983; Plouffe & Stelmack, 1984). If the proposed association between memory and P300 is correct, then it is expected that pictures, which are better remembered than words, will elicit larger amplitude P300 waves than words during the acquisition phase.

A negative wave that develops at about 400 ms has been shown to be an exquisite index of linguistic activity, particularly semantic expectancy/constraint (Kutas & Hillyard, 1980a; Kutas & van Petten, 1989). In the present case, it was of interest to determine whether this negative wave would distinguish words from pictures that have the same denotative meaning, that is, a distinction made on the basis of physical representation rather than meaning. In their seminal paper, Kutas and Hillyard (1980b) demonstrated that words at the end of a sentence that were larger in size (physically different) than the preceding words elicited a P300 wave, whereas words that were not congruous with the meaning of the preceding words elicited an N400. In this case, the effect was determined by the contrast of physical and linguistic differences. Subsequent work has extended the conditions under which an N400 is observed from semantic sentence incongruity to include semantic priming (Bentin, McCarthy, & Wood, 1985) and phonological and orthographic processing (Rugg, 1984), although the identity of the wave under these different conditions is controversial. Moreover, it has been claimed that an anterior negative wave in the 300–500 ms latency range may be elicited when an unpredictable picture must be named or when visual objects are rotated (Stuss, Sarazin, Leech, & Picton, 1983; Stuss, Picton, & Cerri, 1986), effects which suggest that the N400 is not specifically linguistic. In the recognition memory task, the linguistic sensitivity of the N400 would be expressed in larger amplitude for words than for pictures. On the other hand, if N400 is a general feature of the evaluation of any complex stimulus (Stuss et al., 1983, 1986), then the N400 may not distinguish pictures from words.

Method

Subjects

The subjects were 40 right-handed university students, 20 women and 20 men, aged 19–35 years. All subjects reported normal or corrected-to-normal vision, and all were naive with respect to the stimulus material and the procedures employed in the experiment. Subjects were assigned, at random, to one of four conditions in which they were required to perform a recognition memory task: (1) intentionally learned pictures, (2) intentionally learned words, (3) incidentally learned pictures, and (4) incidentally learned words. There were 5 women and 5 men in each condition. Electrodes were applied prior to the acquisition phase of the recognition memory task and EEG was recorded during both acquisition and recognition memory phases.

Recognition Memory Task

The picture stimuli were photographic slides of unambiguous, black line drawings, which were prepared from children's colouring books (Stelmack et al., 1983). The word stimuli were slides of horizontally presented concrete nouns, displayed in black, uppercase pica font. The words and pictures had corresponding denotative meanings.

The stimuli were projected onto a white wall in the laboratory by a Kodak slide projector (Model 850). A second projector presented a blank slide between stimulus presentations. Stimulus onset, which occurred every 5 s, was initiated by a Cromemco Z-2 microcomputer. A tachistoscopic shutter and a Lafayette timer were modified to control both stimulus duration, 2 s, and the synchrony of the two projectors such that the offset of the stimulus slide initiated the onset of the blank interstimulus slide. This method was employed to maintain a constant level of luminance that minimized confounding visual ERPs generated by changes in light intensity at stimulus onset. An RCA video camera relayed the slide projected image to a 22 cm video monitor placed 1.5 m from the subject. Pictorial stimuli, on average, subtended a horizontal visual angle of 5 degrees, and a vertical visual angle of 3 degrees. The visual angle of the word stimuli was 4 degrees horizontal, on average, and 1 degree vertical.

In the acquisition series, one of two sets of 140 items, set A or set B, was presented. Each set consisted of 70 words and 70 pictures ordered randomly. The denotative meaning of the items in each set were counterbalanced, such that the denotative meaning of the words in set A corresponded to the pictures in set B and the pictures in set A corresponded to the words in set B. Half of the subjects were instructed to try to remember the pictures and to disregard the words; they were informed that we were interested to see if the words interfered with remembering the pictures. The other half of the sample was instructed in a similar manner but they were informed that the words were to be remembered and the pictures to be ignored. These instructions were counterbalanced for set A and set B.

The recognition memory test followed the acquisition phase after a 10-min rest period. Subjects were tested for recognition memory of either picture or word items that they were instructed to remember, or picture or word items that they were instructed to ignore. Four comparison groups resulted: an intentional picture group, in which the subjects were instructed to remember pictures and were tested for the pictures; an incidental picture group, in which the subjects were instructed to remember words but were tested for pictures; an intentional word group, in which the subjects were instructed to remember words and were tested on words; and an incidental word group, in which the subjects were instructed to remember pictures but were tested on words. All subjects were required to discriminate 70 target items that were previously shown from 70 distractor items that were not previously shown. The target and distractor items were presented in a computer generated Bernoulli random sequence. A yes/no signal detection procedure (Green & Swets, 1966) was used. The subjects indicated their decision by pressing the appropriate button on a response panel.

The hand used to make the response was counterbalanced across groups. Subjects were required to make their response during the 2-s period that the stimulus was present, a constraint that was imposed to allow computer sorting of EEG epochs according to the four response categories: hits, misses, false alarms, and correct rejections. The proportion of hits and false alarms was used to obtain a measure of recognition memory (d′) that was relatively free of response bias.

ERP Recording

The EEG was recorded using 10 mm Beckman Ag/AgCl electrodes affixed to the scalp at F_Z, C_Z, P_Z, O_Z, C_5, and C_6 according to the International 10/20 system. Each scalp electrode was referred to a balanced noncephalic sternovertebral site (Stephenson & Gibbs, 1951). The EOG was recorded from electrodes placed on the lateral extremity of the supraorbital ridge of the left eye and the infraorbital ridge of the right eye. This permitted the monitoring of both horizontal and vertical eye movement on a single channel. Inter-electrode impedances were below 2 kOhm.

EEG and EOG signals were amplified using Nihon Kohden EU/5D polygraph amplifiers. For all channels, the high filter was set at 35 Hz and the time constant was set at 0.3 s. This relatively short time constant increases the likelihood of summation of sustained negative potentials with the late slow components (Picton, Woods, & Proulx, 1978). Analog-to-digital conversion was carried out at a 6-ms sampling rate by the Cromemco Z-2 microcomputer. Signal averaging of EEG and EOG was performed on-line (Makasare, Campbell, Stelmack, & Knott, 1985) for 1.8 s, beginning 0.3 s prior to stimulus onset. Trials were rejected prior to averaging when the signal exceeded $\pm 100\ \mu V$ on either the EOG or F_Z channels. Trials were also rejected if the subject's response occurred outside of the sweep time. The averaged data were stored on diskette for off-line plotting and scoring.

ERP Measurements

Four waves of the averaged evoked response were clearly evident for all subjects; these waves were quantified using a computer scoring algorithm. The waves were labelled in terms of their polarity and prominent peak latency. Latency windows were derived from the morphological and topographical characteristics of the grand average waveforms obtained during the acquisition phase. The maximum positive deflection occurring between 220 and 280 ms was termed P250. The latency for this wave was determined at F_Z ($\bar{X}$=243 ms), where it was most prominent, and amplitudes for all sites were measured at that latency. The maximum positive deflection occurring between 280 and 450 ms from stimulus onset was termed P350. The latency for this wave was determined at P_Z ($\bar{X}$=342 ms) where the peak was most prominent, and amplitudes for all sites were measured at that latency. The maximum negative wave between 400 and 600 ms from stimulus onset was termed N450. Latency was measured at F_Z ($\bar{X}$=485 ms) where this peak was most prominent and amplitudes for all sites were measured at that latency. The maximum positive peak between 480 and 700 ms was called P600. Latency was measured at P_Z ($\bar{X}$=563 ms).

Results

Recognition Memory Performance

The mean recognition memory score, d′, was greater for intentionally learned pictures, 3.2 (SD=0.9), than for intentionally learned words, 2.2 (SD=0.8), $t(18)=2.5$, $p<.05$, and recognition memory for incidentally learned pictures, 1.8 (SD=0.5), was greater than for incidentally learned words, 1.3 (SD=0.4), $t(18)=2.34$, $p<.05$. All group differences were significant except for the intentional word versus incidental picture comparison.

ERP Waveform Analyses

Each wave at each electrode site was analysed independently for all treatment comparisons with programs from the *BMDP Statistical Software* manual (Dixon, 1983). Individual comparisons between means were made with the Tukey test. The .05 level of confidence was applied to all statistical tests. Conservative confidence levels were adopted for factors having repeated measures.

Given that stimulus type was a within-subject factor at acquisition but a between-subjects factor during the recognition test, the first analysis examined the effects of stimulus type (picture, word) and learning condition (incidental, intentional memory instruction) on ERP waveforms only during the acquisition phase. In this case, a two-way ANOVA was applied to the ERP data, with learning condition as the independent group factor and stimulus type as the repeated measures factor (both pictures and words were presented to each subject in the acquisition phase). The ERP waveforms obtained in the acquisition phase are shown in Figure 1 and the corresponding means for the ERP components are shown in Table 1.

In a second analysis, differences in ERP waves during the recognition phase were examined by applying a three-way ANOVA with repeated measures. In these analyses, both stimulus type and learning condition were independent group factors; the within-subject factor comprised two response categories, hits and correct rejections. The small number of items in the false alarm and miss response categories that were obtained during the recognition memory test, particularly for pictures, precluded analysis of the ERP waveforms in those categories. The ERP waveforms obtained for items in the hit response category for pictures and words are shown in Figure 2 for both the intentional and incidental conditions and similarly in Figure 3 for the correct rejection response category.

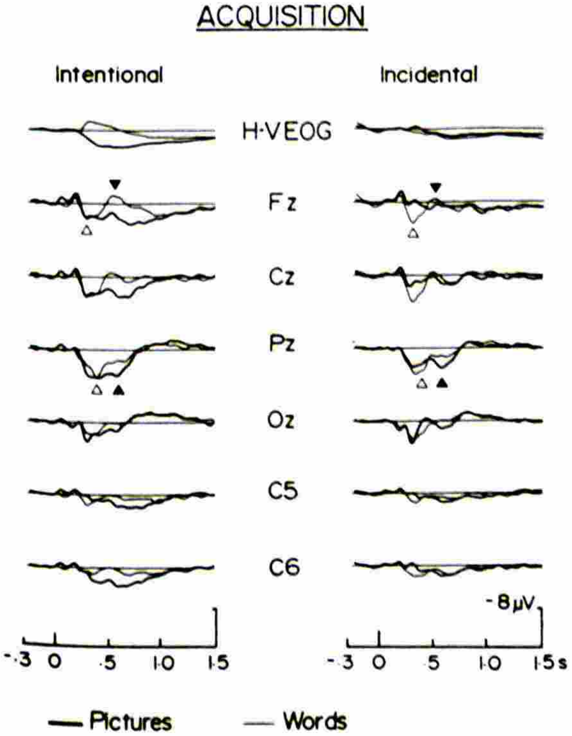

Figure 1. ERP waveforms for pictures and words during acquisition with intentional and incidental learning instructions. EOG is plotted at half gain in this and other figures. P250 is indicated by the open triangle at F_Z, P350 by the open triangle at P_Z, N450 by the closed triangle at F_Z, and P600 by the closed triangle at P_Z.

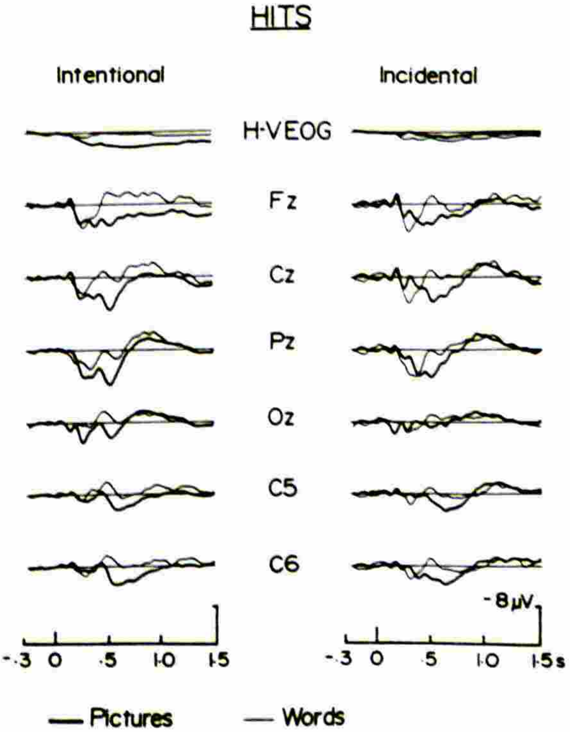

Figure 2. ERP waveforms for pictures and words that were hits during the recognition memory test following intentional and incidental memory instructions.

Because all subjects were shown both pictures and words during the acquisition phase but only half of the subjects were tested for pictures and half tested for words during the recognition phase, it was necessary to assess the differences in ERP waveforms between the acquisition and recognition phases in independent analyses for pictures and words. In these two analyses, a two-way ANOVA with repeated measures was applied in which learning condition was the independent groups factor and acquisition, hits, and correct rejections defined the repeated measures factor.

P250. During acquisition, the P250 latency was shorter for pictures ($\overline{X}$=241 ms) than for words ($\overline{X}$=249 ms) at F_Z, $F(1/38)=8.91$. Significant main effects for stimulus type were observed for P250 amplitude, with the words eliciting larger amplitude than the pictures: at F_Z, $F(1/38)=19.29$; at C_Z, $F(1/38)=8.93$; at C_5, $F(1/38)=14.03$; and at C_6, $F(1/38)=8.14$. Individual comparisons between means indicated that P250 amplitude was larger to words than to pictures for both the intentional and the incidental items at C_5. Analysis of the Stimulus Type × Learning Condition interaction at F_Z revealed that words elicited larger amplitude than pictures only in the incidental learning condition, $F(1/38)=4.11$. Similarly, individual comparisons between means indicated that the main effects at C_Z and C_6 were determined primarily by the smaller amplitude to pictures than to words in the incidental learning condition. During the recognition memory test, P250 amplitude was larger for words than for pictures, at F_Z, $F(1/36)=10.01$, and at C_6, $F(1/36)=4.90$. These differences between pictures and words were evident with both the intentional and incidental items and with both hit and correct rejection response categories. For F_Z, the effects were more pronounced for comparisons of incidental items, where P250 amplitude for pictures was attenuated, but P250 was also larger for words than for pictures with intentional items in both the hit and correct rejection categories. In general, then, words elicited larger P250 amplitude than pictures quite consistently at F_Z, and differences were also apparent at lateral placements during acquisition and recognition phases (C_6).

There were no differences between intentional and incidental conditions for the P250 wave for words. However, during the acquisition phase, P250 amplitude at F_Z was greater for pictures in the intentional condition than for pictures in the incidental condition, $F(1/38)=4.11$. Thus, directed

Table 1

Mean ERP amplitude for pictures and words in the intentional and incidental conditions of the acquisition phase

	Mean ERP Amplitudes (μV) (SDs in Parentheses)			
	Intentional Condition		Incidental Condition	
Site	Words	Pictures	Words	Pictures
		P250		
F_Z	4.86 (3.65)	3.61 (4.45) c*	4.82 (4.12) s*	1.55 (2.44)
C_Z	5.30 (4.39)	5.24 (4.77)	6.18 (4.48) s*	2.93 (2.83)
P_Z	4.47 (4.70)	5.23 (3.61)	4.91 (4.50)	3.34 (4.23)
O_Z	3.21 (3.46)	3.72 (2.66)	3.66 (3.11)	3.52 (3.35)
C_5	3.07 (1.76) s*	0.79 (3.34)	2.81 (2.95) s*	0.46 (1.99)
C_6	1.50 (3.40)	1.24 (3.10)	2.72 (3.12) s*	0.00 (2.07)
		P350		
F_Z	3.17 (3.80)	4.49 (3.11)	3.42 (3.58)	2.41 (3.56)
C_Z	4.40 (4.13)	5.22 (3.17) c*	4.37 (4.18)	2.67 (3.90)
P_Z	6.41 (4.09)	7.32 (3.04) c*	5.82 (3.41)	4.36 (3.50)
O_Z	3.03 (3.32)	3.62 (2.72)	3.33 (3.50)	1.58 (3.29)
C_5	2.03 (3.38)	2.28 (1.98)	2.26 (2.10)	1.75 (2.66)
C_6	2.11 (3.23)	3.52 (2.26)	2.68 (2.72)	2.04 (2.70)
		N450		
F_Z	−2.70 (2.22) s*	−0.27 (2.89)	−2.48 (2.75)	−2.08 (2.60)
C_Z	−2.07 (2.14) s*	0.63 (3.59)	−2.05 (2.77)	−1.58 (2.80)
P_Z	0.67 (2.53) s*	2.64 (3.75) c*	−0.09 (2.86)	0.74 (3.06)
O_Z	−0.41 (1.81)	0.32 (2.69) c*	−1.01 (1.76)	−1.18 (2.32)
C_5	−0.76 (1.98)	−0.15 (2.09)	−0.70 (1.57)	−0.82 (2.52)
C_6	−0.72 (2.68) s*	0.73 (2.09)	−0.83 (1.92)	−0.32 (2.31)
		P600		
F_Z	2.42 (2.79)	3.23 (2.31)	1.53 (2.83)	2.67 (2.39)
C_Z	3.22 (3.05) s*	4.89 (2.41)	2.80 (1.92)	3.77 (2.24)
P_Z	4.46 (2.60) s*	6.24 (2.57)	4.14 (1.88) s*	5.51 (1.92)
O_Z	1.55 (1.66) s*	2.72 (2.08)	1.79 (1.78) s*	2.48 (1.40)
C_5	2.49 (1.94)	2.75 (1.66)	1.92 (2.06)	3.10 (1.50)
C_6	2.38 (2.08) s*	3.39 (1.91)	2.16 (1.88)	3.55 (2.30)

Note. Significant differences between pictures and words are indicated by "s*"; significant differences between intentional and incidental pictures are indicated by "c*."

attention had a differential effect on frontal positive amplitude for pictures but not for words.

P350. During the acquisition phase, P350 amplitude was also larger for intentionally learned pictures than for incidentally learned pictures, at C_Z, $F(1/38)=6.95$, and at P_Z, $F(1/38)=16.04$. During the recognition memory test for pictures, the P350 amplitude was greater for hits than for correct rejections at F_Z, $F(1/36)=4.43$, and at C_Z, $F(1/36)=7.16$, in both the intentional and incidental conditions. P350 amplitude was also greater with intentional pictures for hit ERPs than for acquisition ERPs at P_Z, $F(1/36)=5.43$. Overall, this P350 wave distinguished intentional from incidental pictures during the acquisition phase and was sensitive to the recognition decisions for pictures during the recognition memory test. There were no differences in P350 between intentional and incidental conditions for words. The effects of the intentional/incidental manipulation on the acquisition waveforms for each stimulus type are illustrated in Figure 4.

N450. In the acquisition phase, N450 amplitude was greater for words than for pictures: at F_Z, $F(1/38)=6.78$; C_Z, $F(1/38)=6.42$; P_Z, $F(1/38)=6.10$; and C_6, $F(1/38)=4.98$. Stimulus Type $\times$ Learning Condition interactions were also observed at P_Z, $F(1/38)=5.52$, and O_Z, $F(1/38)=5.14$. Individual comparisons between means for these main effects and interactions indicated that these N450 differences between pictures and words were significant only under the intentional set condition. In addition, the Stimulus Type $\times$ Learning Condition interactions at P_Z and O_Z indicated that pictures in the incidental condition elicited greater negative amplitude than pictures in the intentional condition. There were no other significant main effects

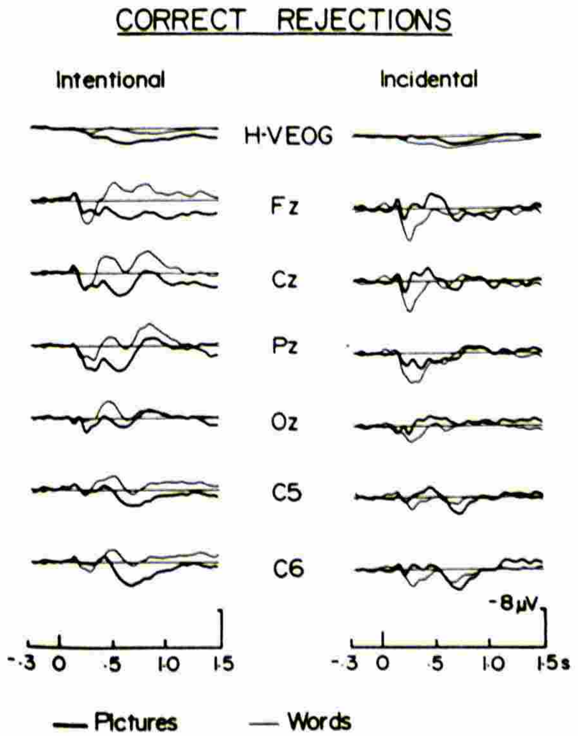

Figure 3. ERP waveforms for pictures and words that were correct rejections during the recognition memory test following intentional and incidental memory instructions.

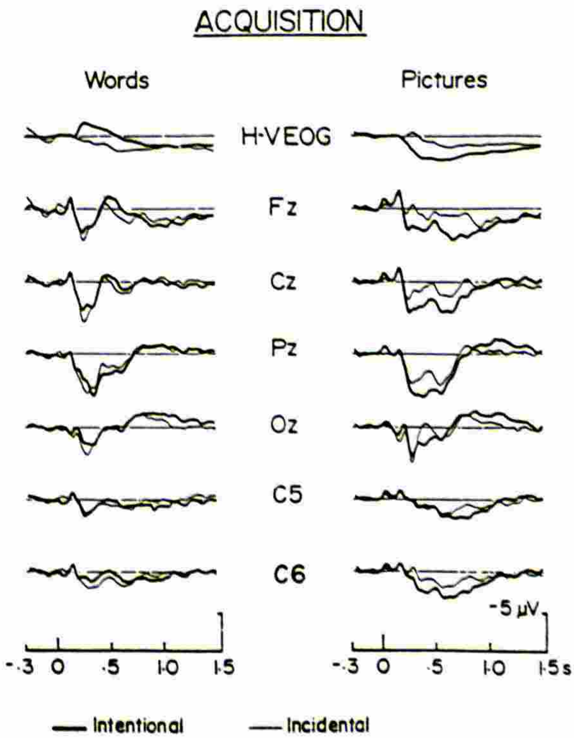

Figure 4. ERP waveforms comparing intentionally and incidentally learned pictures and words obtained during the acquisition phase.

or interactions due to intentional/incidental instructions on the ERPs to words or pictures presented in the acquisition phase.

During the recognition phase, greater N450 amplitude for words than for pictures was observed at P_z, $F(1/36) = 7.75$, and C_5, $F(1/36) = 4.99$, across both conditions and response categories. Stimulus Type × Response Category interactions were also observed in which the N450 amplitude was larger for words than for pictures for ERPs averaged in the hit category at F_z, $F(1/36) = 5.61$, and C_6, $F(1/36) = 5.16$, for both the intentionally and incidentally learned items. In general, then, N450 amplitude was larger at fronto-central and posterior placements for target words than for target pictures during acquisition (intentional condition) and during the recognition memory for intentional items (both hits and correct rejections) and incidental items (hits). The greater N450 amplitude for words than for pictures was also evident at posterior placements during the recognition memory phase.

In the recognition phase, analysis of the N450 wave for the correct rejection items revealed a Stimulus Type × Learning Condition interaction at F_z, $F(1/36) = 5.58$, and at P_z, $F(1/36) = 7.03$. For pictures, the N450 amplitude for correct rejections was larger for the incidentally learned pictures than for the intentionally learned pictures. For words, this effect was reversed, with greater N450 amplitude for the intentional words than for the incidental words in the correct rejection category.

The N450 wave also differentiated within stimulus types across the acquisition and recognition phases. In the incidental learning condition, larger N450 amplitude for pictures was observed for the correct rejection than for the acquisition and hit items at all electrode sites: F_z, $F(1/36) = 6.69$; C_z, $F(1/36) = 6.60$; P_z, $F(1/36) = 4.01$; O_z, $F(1/36) = 5.52$; C_5, $F(1/36) = 5.79$; and C_6, $F(1/36) = 9.29$. For words, the N450 for correct rejections was greater than in the acquisition phase at O_z, $F(1/36) = 3.74$, and C_5, $F(1/36) = 6.35$, in the intentional condition.

P600. For the P600 wave, significant main effects of stimulus type were observed, with greater amplitude for pictures than for words: at C_z, $F(1/38) = 5.40$; P_z, $F(1/38) = 14.20$; O_z, $F(1/38) = 7.80$; and C_6, $F(1/38) = 8.35$. Individual comparisons between means indicated that the P600 amplitude for intentionally learned pictures was larger than for intentionally learned words at those electrode sites and that the P600 amplitude for incidentally learned pictures was larger than for incidentally learned words at P_z and O_z. In the recognition phase, P600 amplitude was also larger for pictures than for words with intentional items for both hit and correct rejection categories and with incidental items in the hit category at P_Z, $F(1/36)=5.08$, and at C_6, $F(1/36)=8.02$. For both pictures and words, moreover, the P600 was greater for hits than for correct rejections at F_Z, $F(1/36)=5.20$, and at C_Z, $F(1/36)=5.46$. There were no significant differences between intentional and incidental learning instructions for P600 during either the acquisition or recognition phases.

Discussion

Recognition memory for pictures was superior to recognition memory for words having the same denotative meaning. This result replicates previous reports (e.g., Standing et al., 1970) and provides a suitable behavioral context for examining the ERPs that were recorded concomitantly. Intentional learning led to performance that was superior to incidental learning for both pictures and words. These findings clearly indicated that the instructions to remember or ignore the items had the desired effect on recognition memory; they also define appropriate conditions for assessing the influence of directed attention on ERPs during the acquisition phase of recognition memory performance, as well as for assessing the consequences of those manipulations on the recognition memory test.

Words were consistently associated with greater P250 amplitude than pictures at anterior and lateral placements during both acquisition and recognition phases, an effect that indicates early processing differences between the two stimulus types. For pictures, the P250 was differentially sensitive to the instruction to attend or to ignore at acquisition as evidenced by the smaller P250 during incidental than during intentional learning. The instruction to attend also appears to have attenuated differences between pictures and words in the intentional condition. The P250 for words was not affected by instructions to attend, ignore, or recognize. This suggests that attentional mechanisms may be implicated in this early stimulus processing that distinguishes pictures from words.

During the acquisition phase, pictures that were ignored were characterized by attenuated P250 at anterior and central sites, attenuated P350 at central and parietal sites, and greater N450 at parietal and occipital sites, compared to pictures that were attended. There were no effects of attention on the waveforms for words. This finding is consistent with the view that early processing becomes automatic for words but not for pictures. An automatic process would be relatively unaffected by attentional demands and would appear equivalent during both intentional and incidental processing of a stimulus. Saccadic eye movement studies (Jolicoeur et al., 1984), picture/word interference tasks (Sperber et al. 1979), and priming studies (Lupker, 1979) indicate that much of the early phonological and lexical processing of words is automatic. The pattern of results obtained is consistent with this view. However, because the early waves discussed here, P250 and P350, do not differentiate between pictures and words in the intentional learning condition, nor between words of the intentional and incidental conditions, the differences in memory performance observed for those conditions cannot be attributed to these waves.

Salient ERP effects that distinguished pictures from words were also prominent in the N450/P600 wave complex. In general, words elicited a greater fronto-central and parietal negativity than pictures in this latency range. Although there is little precedent for the direct comparison of picture and word waveforms in a recognition memory paradigm, the data describe a robust effect that was evident with intentional instructions during both the acquisition and recognition memory phases. Effects congruent with the present data have been observed in a lexical decision task in which subjects were required to discriminate words from non-words and objects from non-meaningful line drawings (Campbell, Karam, & Noldy-Cullum, 1987). Both words and non-words elicited greater N400 amplitude than pictures and non-pictures at posterior sites, and a positive parietal wave at 520 ms was also greater for pictures than for words. There is some convergence of this effect with data reported in an analysis of hemispheric differences during a category matching task for pictures and words, although both the task and the analytical methods differ considerably from those employed in the present study (Kok & Rooyakkers, 1986). In the first session of their study, a posterior positive peak was of larger amplitude for pictures than for words; the effect was not sustained in a repetition of the protocol. Inspection of the waveforms of that experiment also indicates an enhanced negativity for words than for pictures at about 540 ms, but this was not a statistically significant effect.

Because the N450 and P600 occurred within overlapping latency ranges, it is difficult to determine the extent to which these effects were influenced by summation or interaction of these potentials. It should also be noted that in the present case, the amplitude of the N450 for words was maximum at anterior placements during acquisition rather than at the parietal sites reported by Kutas and Hillyard (1980c). If the two waves do refer to the same process, the differences in scalp topography likely stem from the procedural differences that distinguish this work. It seems that an N400 that is maximum at posterior placements is consistently observed to linguistic stimuli that are not congruent with the context of sentences (e.g., Kutas & Hillyard, 1980; Polich, 1985; Neville et al., 1986), whereas an N400 that is maximal at anterior electrode sites is observed when graphic or linguistic items are presented in sequences that do not manipulate linguistic congruity, as in the present case (e.g., Stuss et al., 1986; Campbell et al., 1987).

Overall, the larger N450 amplitude for words than for pictures, specifically as observed with intentional items during acquisition, hits and correct rejections, and with incidental items in the hit category, is consistent with the linguistic sensitivity that has been ascribed to the N400 wave (Kutas & van Petten, 1988). However, the picture and word items had the same denotative meaning and therefore the differences in the N450 wave between these stimulus types are attributed to differences between the verbal and physical representations of the items rather than to analysis of meaning or context incongruity. Because the N450 wave clearly differentiated pictures from words, these data do not confirm the suggestion that the N400 wave is a general feature of the evaluation of any complex stimulus (Stuss et al., 1983; Picton & Stuss, 1984), an inference that was based on the absence of differences between words and pictures in a naming task. It may be that the repetition of words and pictures in their procedure served to attenuate the N400 amplitude to words and diminish the effect (cf. Rugg, 1985).

With regard to memory and P600, it was expected on both theoretical and empirical grounds that pictures, which are better remembered than words, would elicit larger P600 amplitudes. This P600 wave has the scalp topography expected of the P300 observed for novel, task-relevant events, and the latency is in agreement with that observed for complex tasks, including memory for linguistic stimuli (e.g., Karis et al., 1984). The greater P600 amplitude for pictures than for words during acquisition, in both the intentional and incidental conditions, is consistent with the previously reported association of enhanced P300 amplitude with better memory. It is notable, however, that P600 did not distinguish between intentional and incidental conditions for either pictures or words. Thus, to the extent that P600 is indicative of differences in the memorability of pictures and words during acquisition, the influence of directed attention was not reflected in that effect. In this regard, it is claimed that the relationship between P300 and memory emerges more consistently when incidental learning procedures are employed (Karis et al., 1984; Fabiani et al., 1986; Neville et al., 1986; Paller et al., 1987; Paller et al., in press). In all of these cases, however, an intentional learning condition was not employed and without this comparison it cannot be determined whether the incidental learning instruction did, in fact, facilitate the effect.

Although there is considerable evidence linking enhanced amplitude of a positive wave in the 480–700 ms latency range with better memory for linguistic stimuli, a clear understanding of this association has not yet been achieved. In the present study, the greater P600 amplitude for pictures than for words is not direct evidence of the association of P600 and memory, but rather is inferred from the better memorability of pictures. An alternative strategy that has been more commonly employed compares the ERP waves to items that were subsequently remembered with the ERP waves to items that were not remembered during the performance of memory or decision tasks. The von Restorff effect, in which recall for isolated, infrequent, and larger sized words is superior to the recall of frequent and smaller words, was employed to explore the association of P300 and better memory (Karis et al., 1984). In that study, the von Restorff effect was exhibited only by subjects who used rote memory strategies. P300 amplitude was greater for items that were better remembered, but did not distinguish between the isolated and more frequent words. That is, the ERP analysis did not converge with the memory effect. Comparable results were observed in a similar study that required subjects to distinguish between male and female names (Fabiani et al., 1986). Likewise, Neville et al. (1986) reported that words that were congruous with the preceding context were better remembered than incongruous words and that words that were better remembered elicited larger amplitude (P650) than words not remembered. Again, however, this wave did not distinguish between the congruous and incongruous words, so the distinction that influences memory did not converge with the positive ERP wave.

In a series of studies, the difference between late positive ERP waves (Dm) for words that were remembered or forgotten was used to examine encoding in memory during semantic processing tasks (Paller et al., 1987; Paller et al., in press). Words that required a semantic decision were better remembered than words in letter identification tasks, an effect that converged with larger late positive ERP differences (Dm) for remembered than for forgotten items across tasks. It was also clear from the analysis of these data that factors other than semantic decision, such as affirmative decisions, contributed to the ERP effect. Moreover, the authors argue persuasively for the dissociation of Dm and

P300 on the basis of differences in scalp topography and in their relations to several task parameters. Overall, there is rather compelling evidence that implicates variation in this late positive ERP wave with memory performance, but further evidence is required to establish its functional significance.

ERPs were recorded during both the acquisition and recognition memory phases. Putatively then, the waves that distinguish pictures from words during the task may be independently referred to both encoding and retrieval operations. This contrasts with recall experiments in which the waves are recorded during only the acquisition phase. The same general pattern of differences between pictures and words that were observed during the acquisition phase were observed during the recognition phase, at least in regard to the hit decisions. That is, words elicited greater P250 amplitudes than pictures at anterior and lateral placements. The greater N450 amplitude for words than for pictures during the acquisition phase in the intentional condition at frontal, central, and parietal placements was observed during the recognition phase at central and parietal placements. The enhanced P600 for pictures was also observed parietally. Overall, these differences in ERP waves between pictures and words observed during acquisition and those to the hit items in the recognition memory test are congruent. To the extent that these ERP waves reflect differences in the cognitive processing of pictures and words, the effects are common to both encoding and retrieval.

In the recognition memory phase, it was assumed that target items from the incidental learning condition, which are not subject to effortful processing, would be more difficult to retrieve than items from the intentional condition. As evidenced by the performance measures, the incidental learning task was clearly more difficult than the intentional task for both pictures and words. These behavioural effects were not paralleled by comparable ERP effects for target items in the hit category. That is, there were no ERP differences between the intentional and incidental conditions for items in the hit category for either pictures or words. Thus, difficulty of memory search cannot be a contributing factor to the development of recognition memory ERP waves, at least with respect to the hit items. For correct rejection items, however, there was a notable interactive effect between incidental and intentional conditions, which was observed in the N450 to pictures and words. In general, the ERPs for pictures in the incidental condition that were correctly rejected were characterized by increased frontal and parietal negativity compared to the ERPs for the pictures that were correctly rejected in the intentional condition. For words, the opposite effect emerged with decreased N450 at these sites for the words in the incidental condition that were correctly rejected compared to the words in the intentional condition that were correctly rejected. This is a puzzling effect that is difficult to interpret convincingly either in terms of difficulty of memory search or response bias. N450 appears to be differentially sensitive to pictures and words in the way that we make decisions about the absence of elements in memory. What this process might be, and whether the effect is confounded by an overlapping positive wave, is a matter for future investigation.

Reliable differences in ERP waveforms were observed in the recognition memory phase that distinguished the hit from the correct rejection decisions. The P600 was consistently larger for hit items than for correct rejection items for both pictures and words across both intentional and incidental conditions, an effect that concurs with several previous observations in recognition memory tasks (Johnson et al., 1985; Neville et al., 1986; Stelmack, Saxe, Noldy-Cullum, Campbell, & Armitage, 1988). There has been some speculation that this effect is indicative of differences in the degree of confidence that may be associated with the decisions (cf. Neville et al., 1986). Because the P600 wave did not distinguish between items of the intentional and incidental conditions for either pictures or words, one cannot account for these effects by differences in difficulty of memory search, response bias, or confidence that may characterize differences between the intentional and incidental conditions. It may be that the greater P600 amplitude for hits than for correct rejections stems from the greater signal value or task relevance attached to the hit category by the request to identify those items that were previously presented (Johnson, 1986).

In conclusion, there are differences in ERP waves between pictures and words that are indicative of differences at a relatively early stage of stimulus processing. Attentional mechanisms may be implicated in this processing, because the ERPs for pictures were sensitive to the incidental instructions during acquisition, but the ERPs for words were not. These results are consistent with the view that the early processing of words is automatic (i.e., unaffected by attention), whereas the early processing of pictures is controlled (i.e., influenced by attention). The development of automaticity for many of the processes involved in reading, such as phonological access (Coltheart, 1978) and lexical access (Henderson, 1982; LaBerge & Samuels, 1974; Schneider & Shiffrin, 1977), appears to be the result of overlearning. In the context of the present study, the lower memory performance for words in the incidental condition may stem from retrieval processes, because differences in the ERPs for the intentional and incidentally learned words were evident during the recognition phase but not during acquisition. Pictures and words were also differentiated by a late negative wave which is thought to be especially sensitive to linguistic processing. These effects cannot be attributed to the analysis of denotative meaning because this was equated for pictures and words. Finally, inasmuch as pictures are better remembered than words, the larger P600 for pictures than for words observed during the acquisition phase in this study is consistent with the association between P300 and better memory that was predicted.

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Announcement

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