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The Picture Superiority Effect:
An Event-Related Potential Analysis of Unitary versus Dual Coding Theory

by

Nancy E. Noldy

A thesis submitted to the School of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in Psychology.

Ottawa, Canada, 1987.

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ABSTRACT

Pictures are remembered better than words. One theory to explain this phenomenon suggests that pictorial and verbal information are processed in two different, but connected systems. Another proposes that pictures and words are processed and represented in one common memory system. The two studies presented examine this issue by recording event-related potentials (ERPs) of the brain concurrent with performance of a recognition memory task for pictures and words.

The first experiment was a preliminary investigation of ERPs to pictures and words for two independent groups during the recognition memory task. The results of this study raised many questions which were addressed in the second study. Experiment II examined recognition memory for pictures and words under conditions of incidental and intentional learning. As expected, pictures were remembered better than words in both studies. Moreover, intentionally learned stimuli were remembered better than incidentally learned stimuli in the second study. In general, there appeared to be no remarkable difference in the morphology of ERP waveforms for pictures and words. A positive peak at approximately 350 ms was larger for pictures than words in both studies. Two positive peaks at 250 and 350 ms were larger for intentionally than incidentally learned pictures at acquisition but did not differentiate the intentionally from incidentally learned words. This result concurs with evidence indicating that the initial processing of words is automatic, and also suggests that the processing of pictures is controlled. In Experiment II, though not in Experiment I, P600 during the acquisition phase was larger for pictures than words, an effect which is consistent with the evidence associating enhanced P600 amplitude

with better memory. However, there were no differences in P600 amplitude between the incidental and intentional conditions for either stimulus. In both studies, a late negative peak (500 ms) was of larger amplitude in recognition than acquisition waveforms for both pictures and words. This N500 wave seems to be associated with a recognition memory process that is common to both pictures and words. For both stimuli, a late slow wave was larger during the acquisition phase than during the recognition task. In the present ERP analysis of picture and word processes, no support was obtained for the existence of two separate, form-specific systems.

CURRICULUM STUDORIUM

Nancy Elizabeth Noldy was born in Kitchener, Ontario on December 1, 1958. Her Public School and High School education were obtained in Burlington, Ontario. She graduated from Nelson High School in 1976, and obtained a B.A. three years later at McMaster University in Hamilton, Ontario. In 1980 she completed an honours B.A. at the University of Ottawa. All of her post-graduate years in Psychology were spent at the University of Ottawa.

PUBLICATIONS

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INTRODUCTION

Sometimes I put a word in a dark place and have trouble seeing it as I go by. Take the word box, for example. I'd put it in a niche in the gate. Since it was dark there I couldn't see it ... Sometimes if there is noise, or another person's voice suddenly intrudes, I see blurs which block off my images. Then syllables are liable to slip into a word which weren't there originally and I'd be tempted to say they really had been part of the word. It's these blurs which interfere with my recall... (Luria, 1968, p.36-37)

This melding of the verbal and imaginal was characteristic of a young man whose memory capacity seemed limitless. Most of us have difficulty remembering a small proportion of a list of words, while we have much greater success with pictures. However, for Luria's mnemonist, any symbol (word, number, syllable) seemed to be associated with so much information from all of the senses that it was unlikely that he would make a mistake in later recalling or recognizing it. Rarely are words and pictures so synesthetically bound. This case of extraordinary memory capacity is of particular interest to memory psychologists. Why should this enmeshment of verbal and imaginal information lead to such spectacular memory performance? Perhaps there are two different systems, one for words and another for pictures or images. The redundancy created when both are activated may result in increased likelihood of recall. On the other hand, both types of input may share a common abstract representation in memory, but additional information makes the pictorial representation more distinctive. The purpose of the investigations presented in this thesis was to examine the superiority of pictorial over verbal memory using a psychophysiological measure, the event-related potential (ERP).

Despite the plethora of research in this area, the reliance on behavioural outcome measures to infer underlying processes has been a

persistent limitation. Recently, however, there has been some success in the application of psychophysiological methods to problems of verbal learning and memory which promise to provide indices of memory mechanisms that are independent of performance measures. In these studies, the brain's responses to task relevant stimuli are recorded. Typically procedures adapted from cognitive psychology are employed. The brain's responses in such paradigms are often labelled "event-related potentials" or "ERPs". This method allows access to processes which occur while a task is being performed. The two studies presented here use ERPs as measures of the timing and quality of pictorial and verbal information processing. More specifically, differences in ERPs during the performance of recognition memory tasks with pictures and words were examined. Numerous investigators have observed a relationship between ERP waveforms and different aspects of verbal memory functioning. If there are differences in the functional representation of pictures and words in memory, as suggested by the dual-coding theorists, then the functional significance of the ERP waves elicited during memory tasks should be different for pictures and words. If there are no differences in the system of representation for pictures and words in memory, as suggested by the conceptual coding theorists, then the ERP waves should be similarly responsive to memory task demands. That is, changes in the ERP which occur in comparing encoding to retrieval should be similar for pictures and words. Both of these findings have implications for the picture superiority effect.

In two investigations, a recognition memory paradigm is employed in order to compare ERPs observed at encoding (during acquisition) to those elicited at retrieval (during the recognition test). A second comparison is

afforded by the sorting of the subject's response during recognition trials into hits, misses, false alarms and correct rejections. In particular, this sorting allows a comparison of the ERPs for those stimuli which were correctly recognized (hits), to those which were correctly identified as not having been previously presented (correct rejections). The second experiment introduces an additional manipulation. A comparison of intentional versus incidental learning is offered for both pictures and words. In the incidental learning condition, the subject was asked to ignore certain types of stimuli (for example, words). This request usually limits the use of elaborative strategies and reduces memory performance. The incidental learning manipulation allows within-stimulus comparisons of better remembered versus poorly remembered stimuli and strategy use versus disregard for stimuli.

The first chapter, a review of the literature, is divided into three major sections. The memory processing differences of pictures and words have been the subject of intensive debate in cognitive psychology. A description of the picture superiority phenomenon, as well as a review of the theoretical issues and the related empirical contributions from cognitive psychology is presented in the first section. The second section of this review will address ERP studies which have employed word or picture stimuli in cognitive tasks in general, as well as the growing number of studies which specifically examine memory processes using this measure. The third section of Chapter I is an examination of methodological and theoretical issues pertaining to the relationship between the picture superiority effect and ERPs, within the framework of the recognition memory paradigm used in these experiments. The utility of ERP waves as dependent measures for examining cognitive

chronometry and memory functioning is discussed.

Chapter II contains the methodology, results and a short discussion of the first study. The methods and results for the second Incidental Learning Paradigm are presented in Chapter III. A discussion follows in Chapter V, relating the combined results for both studies to the hypotheses, and theoretical issues presented in Chapter I.

CHAPTER I

Review of the Literature

The questions addressed in this research are based on two bodies of literature, one from cognitive psychology, and the other from psychophysiology. Is it possible to use event-related potentials (ERPs) to measure picture and word processing differences? What can these differences tell us about why pictorial recognition memory performance is superior to verbal recognition memory performance? The theoretical and empirical literature relevant to the mental chronometry of picture and word processing will be reviewed initially in terms of the cognitive psychology approach (section 1) and then the relevant ERP studies (section 2) and utility of ERPs to address these issues (section 3) will be supported.

The Picture Superiority Effect

This first section of the literature review addresses the problem of picture superiority as it has traditionally been examined in cognitive psychology. The major theoretical models of picture and word processing are described, and their explanations for the picture superiority effect are outlined. Subsequently, empirical evidence which bears on the mental chronometry of pictorial and verbal memory processes is presented. Finally, methodological issues are addressed.

The investigation of memory for verbal stimuli has long predominated experimental psychology since the early classical studies of Ebbinghaus. Interest in picture memory research developed later, when Shepard (1967) revealed that pictures could be recognized with extremely high accuracy. Further investigations revealed that an almost unlimited quantity of information can be retained in pictorial form (Kroll & Potter, 1984;

Postman, 1971; Sperber, McCauley, Ragain & Weil, 1979; Standing, Conesio & Haber, 1970). Even when the number of stimuli is large, and stimuli are presented at exposure times as short as 20 ms (Noton & Stark, 1971), recognition is maintained at a high rate for several days (Nickerson, 1968; Shepard, 1967; Standing, Conesio & Haber, 1970) and may remain above chance for a full year (Fajnstzèjn-Pollack, 1973; Nickerson, 1968).

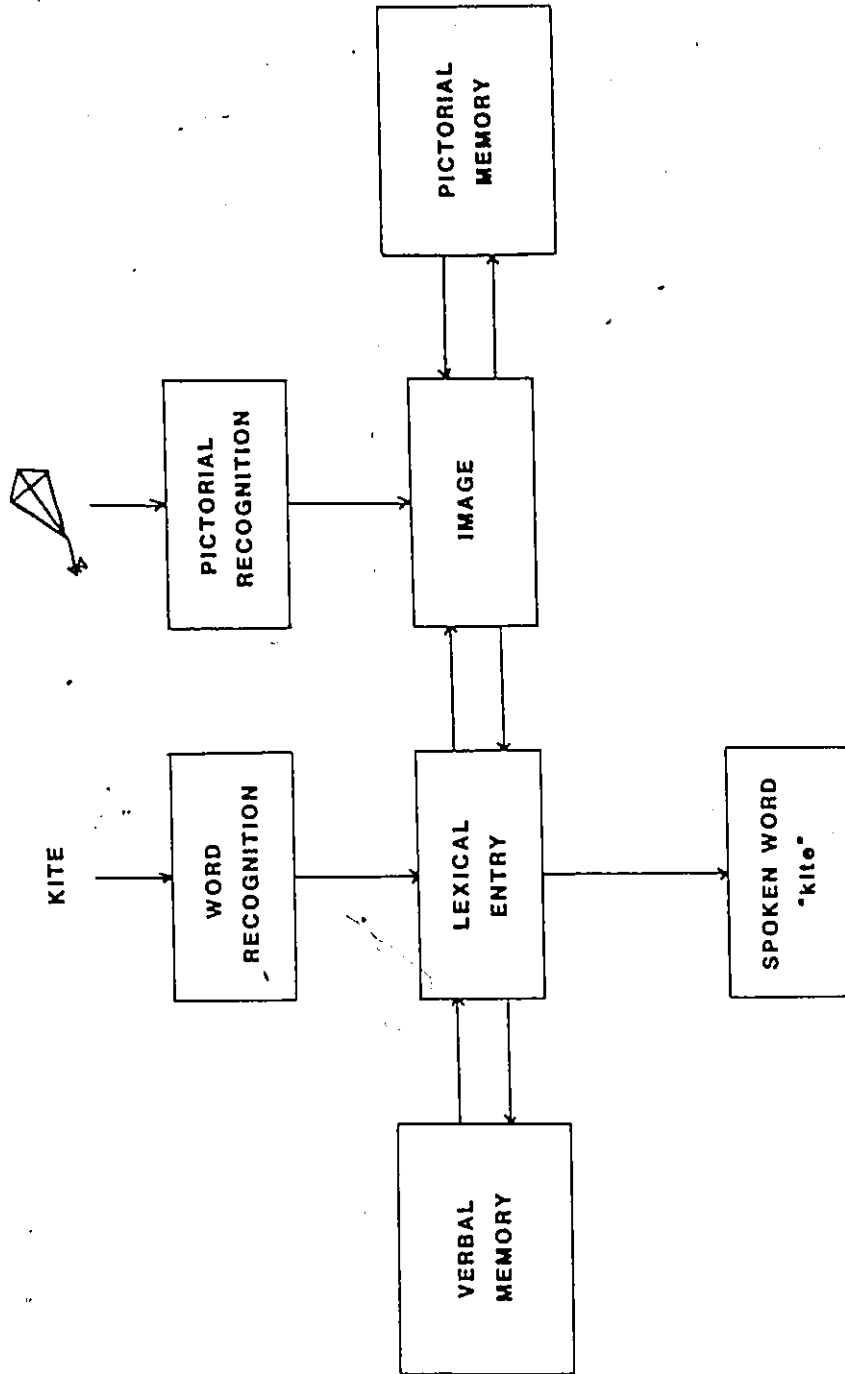
Explanations of Picture Superiority

Dual coding theory

Dual coding theory (Paivio, 1971, 1986) distinguishes between two systems of mental representation. One system is a verbal, language-based hierarchy of associations. The other system processes nonverbal information in a representational network of images (see Fig.1.1). Words are first processed in the verbal system. With extra processing time, the associated image may be generated. On the other hand, pictures and objects are first processed in the image-based system, while the associated verbal label may be activated subsequently.

In order to explain the superior memory for pictures compared to words, Paivio suggests that an asymmetry in these two systems exists. An object or a picture, given sufficient processing time, automatically activates its associated verbal label or name. However, words do not necessarily activate their corresponding image. The verbal system can function autonomously of the image system. As a result, representations of pictures are automatically encoded in the image system. Dual coding theorists propose that the superiority of pictorial memory is maintained by the existence of two mental representations rather than just one. Accordingly, instructing subjects to create visual images during the acquisition of words improves their recall

Figure 1.1 A conceptualization of dual coding theory (after Potter, 1979)



(Bower, 1972). On the other hand, abstract words, which are difficult to image are remembered poorly compared to concrete words (Paivio, 1969).

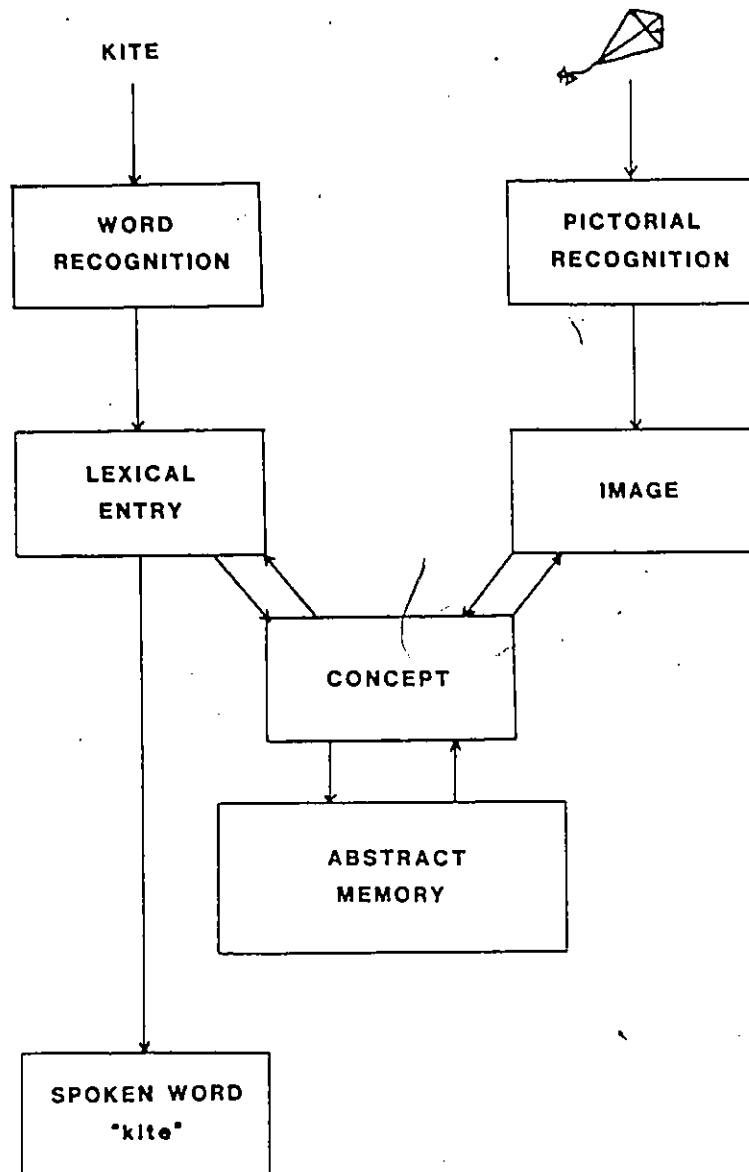
Conceptual coding theory

The conceptual coding theory also accepts the differentiation of separate verbal and nonverbal processes. However, this framework differs from dual coding in that verbal and pictorial memories are stored in the form of a common conceptual representation, accessible by either a word or object (see Fig.1.2). This common system is neither verbal nor perceptual, but more abstract and functionally identical for pictures and words.

The picture superiority effect is generally explained in conceptual coding theory in terms of depth of processing. Recognition and rehearsal of a word might involve processing at a lexical level without further semantic processing. An object or picture, on the other hand, appears to automatically access both the pattern-recognition and conceptual meaning levels. In this model, naming a picture requires prior analysis for meaning. Thus, in contrast to dual coding theory, semantic access is direct for pictures, while naming requires further controlled processing. Pictures are better remembered than words because they are more likely to have been processed semantically. Since generating an image of a word requires conceptual processing, this model can also account for the enhancement in memory for imaged words.

The depth of processing explanation has since been modified by Nelson (Nelson, Reed & McEvoy, 1977). These investigators have revised the notion that sensory information should be considered shallow. They acknowledge that sensory features may be very effective in activating memory representations for both words and pictures. Indeed, sensory interference resulting from

Figure 1.2 - A conceptualization of unitary or conceptual code theory (after Potter, 1979)



both visual and phonetic similarity of words affects retrieval. Manipulation of the visual features of pictures leads to similar effects (Nelson, Reed & Walling, 1976). When pictures were chosen such that their visual configuration was similar, the picture superiority effect was eliminated at long presentation rates and reversed at short presentation rates. Since this high similarity affects only recognition performance, but not recall (Nelson, Brooks & Wheeler, 1975), the source of the interference appears to be the retrieval rather than the encoding phase.

In accordance with these results, Nelson and his colleagues developed a "sensory-semantic" model to explain the picture superiority effect (Nelson, Reed & McEvoy, 1977). Retention of both pictures and words is a direct function of both the distinctive and interactive nature of the features at encoding and also the degree to which this context is replicated at retrieval. The greater the degree of overlap between the context or cue at retrieval and that during encoding, the better the chance that the target will be recognized.

Mental Chronometry of Picture and Word Processing

The empirical investigations of picture and word processing are divided here into three categories: studies of word processing, picture processing and finally, studies which have combined the use of picture and word stimuli in order to compare aspects of their processing.

Word processing

In order to examine how early memory-related differences in the processing of pictures and words occur, one body of research has examined the quality of the information obtained from a single fixation period. The eyesmove, on average, every 250 to 300 ms during visual perception (Rayner,

1978). During the saccades or "lapses" of processing, no information is processed by the brain (Latour, 1962; Matin, 1974; Rayner, 1978). Each successive impression is integrated, such that our perception of the stimulus remains constant, despite the inconsistency of the retinal image.

In a series of studies, Rayner (1978) and his colleagues presented a string of letters in parafoveal vision. This stimulus caused eye-movement to the area of the stimulus. When the saccade occurred, a word was presented (foveally) in place of the letter string. The subject's task was to pronounce this second word as quickly as possible. The visual, lexical and semantic relationship of the letter string to the subsequent word were manipulated. Facilitation of word naming was measured by response time. In general, only physical similarity (when the first two or three letters of the word and the letter string were the same) facilitated word naming. As a result of these studies, McConkie and Rayner (1976) hypothesized that an integrative visual buffer stored information and compared each fixation with the previous one. However, when the case of the letters in a word was changed during the saccade, Rayner, McConkie and Zola (1980) found that the facilitation still occurred. One would assume that if a visual buffer existed, less facilitation would have been obtained when the stimuli were physically dissimilar. Overall, results from these studies have indicated that information about words or letters is held in memory across saccades, and that this information is carried at some level of abstraction.

Another issue of word processing addressed by cognitive psychologists concerns the latency of meaning extraction, and whether conscious identification is required prior to the extraction of meaning from verbal and nonverbal stimuli. For fluent readers, many of the processes involved in

reading, such as phonological (Coltheart, 1978) and lexical (Henderson, 1982; LaBerge & Samuels, 1974; Schneider & Shiffrin, 1977) access appear to become automatic as a result of overlearning. However, phonological access may be a prerequisite to lexical access (Rubenstein, Lewis & Rubenstein, 1971). Many studies have indicated that meaning can be extracted very early in the processing of words (eg. Meyer & Schvaneveldt, 1971). However, the precise timing involved in these processes is a contentious issue. The duration of a priming stimulus required before semantic relatedness will facilitate the pronunciation of a target word has been estimated to be as long as 150 ms (Warren, 1972), but as short as 50 ms (Wickens, 1972) or 40 ms (Fischler & Goodman, 1970).

Picture Processing

The perception of meaningful nonverbal stimuli has not been investigated as exhaustively as that for words. In visual short-term memory studies, subjects are generally required to decide whether two pictures that are presented have the same name (ie. matching verbal labels). Responses are made more quickly when pictures are physically identical than when they are physically different even if they represent the same concept. This difference appears to be present at short interstimulus intervals (ISIs), but is eliminated with longer ISIs. These characteristics suggest that the physical or sensory code might be stored in a visual short-term memory.

The visual short-term memory studies do not take into account the relative proportion of information processing time, in terms of fixation periods, for each stimulus. In a series of studies, Pollatsek, Rayner & Collins (1984) examined saccadic eye movements with pictorial stimuli in much

the same way that verbal stimuli were studied by Rayner and his colleagues. They found no difference in facilitation between identical pictures, and those for which the size was altered. In addition, conditions in which the pictures were identical resulted in faster decision times than did either the same-concept condition or a condition in which the mirror-image of the target was previously presented. These results confirm those of the visual short-term memory studies in indicating that some purely visual information is represented across saccades. The information which is integrated across fixations appears to be different for pictorial stimuli than for verbal stimuli. Jolicoeur, Gluck and Kosslyn (1984) conclude that for pictures visual features are integrated, whereas the information held for words is more abstract and independent of physical form, such as letter case.

The eye movement studies also provide support for the contention that naming a picture requires extra processing time subsequent to that required for semantic access. The mirror-image and the same-concept primes were more facilitative than a control condition in which pictures represented different concepts but had identical verbal labels. This combination of results led the authors to suggest that two processes are involved in picture naming, one involving access to visual features, and another which accesses the name. Support for this conclusion, which is consistent with Nelson's sensory-semantic model, has been found in a variety of paradigms. Although drawings take approximately 260 ms longer to name than words, the sorting of drawings into semantic categories is carried out faster (by approximately 50 ms) than a similar sorting of words (Potter & Faulconer, 1975). Thus, for pictures, semantic access appears to require less processing time than phonological access. McCauley, Parmelee, Sperber and Carr (1980) reaching a

similar conclusion, found that naming latencies for picture stimuli which had been preceded by semantically related pictorial primes were significantly faster than unrelated prime conditions. In these studies, the subject's strategy was controlled by excluding any trial in which the prime was verbally reported by the subject.

Comparison studies

Picture/word interference tasks. Studies which compare picture and word semantic priming effects, in general, find asymmetries in processing. Sperber, McCauley, Ragain and Weil (1979), for example, found that the semantic facilitation demonstrated for words was not as great as that for pictures. In addition, when pairs were semantically related, response time was faster for pictures than for words. Conversely, when unrelated pairs were used, the opposite effect occurred. However, these studies, and priming tasks in general, are criticized for assuming that no strategic operation are performed by the subject. The possible intrusion of subjective bias is difficult to predict and interpret.

In an ingenious body of studies, the relative time course of picture and word processing has been examined through the use of a variation on the Stroop (1935) colour-word phenomenon. This version is based on the following general design. The subject is presented with a combination stimulus in which a word is superimposed on a picture. The subject's task is either to name the picture or to read the word. When the task required naming the embedded word, words that labelled the background picture were named more rapidly than when the words belonged to a different semantic category (Lupker & Katz, 1982; Smith & Magee, 1980). This facilitation is limited to situations in which the word and picture represent the same specific concept,

rather than the same conceptual category (eg. animal).

In contrast, when a word is superimposed on a picture from the same semantic category, picture naming latency is prolonged (Lupker, 1979; Rosinski, 1977). Again, an associative relationship does not produce this effect (Lupker, 1979). Furthermore, highly imageable words are more interfering than nonimageable words. Lupker suggests that this pattern of results supports the response competition hypothesis of interference (Dyer, 1973; Keele, 1972; Klein, 1964; Posner & Snyder, 1975; Warren, 1972; 1974). This hypothesis assumes that the subject is actively engaged in processing the response-relevant stimulus property (eg. category, colour), while concurrently engaged in passive or automatic processing of the irrelevant component (eg. word; background stimulus). If task relevant information about the irrelevant stimulus becomes available before the same information about the task relevant stimulus, then the responses to both stimuli will compete for a single motor-output channel. Thus an extra amount of processing time is required to suppress the response to the irrelevant stimulus. Task-relevant semantic information about the background word appears to be available automatically and in competition with similar information about the to-be-named picture. Because naming a word is overlearned, it is likely that access to its name will occur rapidly. Regardless of whether a picture is allowed access to the semantic concept as rapidly as a word, retrieval of the verbal label should require additional processing time. To the extent that the phonological code for a word is available early as a possible response, the competition for motor output will be strong.

The results obtained by Lupker and Katz may be contrasted with the impact

of word processing on the processing of subsequently presented words (Shaffer & LaBerge, 1979), in which the existence of a semantic relationship does influence response latency. The authors suggest that results from priming experiments which reveal such a relationship (eg. Sperber et al., 1979) may be contaminated by strategic operations.

Reality decision tasks. Reality decision tasks for words and pictures have been called "lexical decision" and "object decision" respectively. In lexical decision tasks, subjects are asked to decide whether a string of letters form a real word. In one such study, Vanderwart (1984) compared the extent to which pictures or words could prime the subsequent lexical decision. Pictures which shared the denotative meaning of the target word, facilitated the latency of the lexical decision to the same extent as words (Vanderwart, 1984). This finding concurs with other data indicating that when the task involves semantic processing (eg. categorizing; Durso & Johnson, 1979; Guenther & Klatzky, 1977), rather than naming, pictures can facilitate responses to words. Moreover, the comparable facilitative effects of intra-form and cross-form facilitation support a common unitary memory system, rather than separate form-specific memory systems.

When an object (i.e. picture) decision task, was compared to a lexical (i.e. word) decision task, Kroll and Potter (1984) observed that the response time for both types of decisions was similar. The authors concluded that the objects were not named during the task, since naming pictures is associated with longer response times. This evidence is in direct opposition to Paivio's proposal that pictures are automatically named.

Paired-associate learning: Several studies have employed pictures and words within paired-associate paradigms. Although the results tend to be

contradictory, one common result is that pictures are clearly more facilitating as stimulus cues for words than words are for pictures, or any intra-form pair (Brainerd, Desrochers, & Howe, 1981; Dilley & Paivio, 1968; Paivio & Yarmey, 1966; Postman, 1978). Indeed, pictures seem to increase the difficulty of the task when used as response items (Brainerd, Desrochers & Howe, 1981; Dilley & Paivio, 1968; Postman, 1978). Paivio (1971) has suggested that the demands of the task require transformation of the picture such that a verbal response may be made, and that this decoding may have deleterious effects when the picture is used on the response side of the pair. Brainerd and his colleagues postulated that pictures are better search cues than words, and therefore are more beneficial as stimulus cues. Words, on the other hand, are easier to decode phonologically than pictures, and therefore are an advantage as responses. In addition, they found that after a one week retention interval, pictures were recalled better, regardless of the response required. This effect also appeared to be localized in the later stage of learning. Pairs which included pictures as stimuli did not, unlike the verbal stimuli, have a tendency to regress into a condition whereby they become partially recallable.

Summary

Differences in picture and word processing using behavioural measures may be summarized as follows. The early processing of pictures appears to differ from that of words. Information about words is held in memory over saccades at some level of abstraction, while for pictures, this information appears to be purely perceptual. Phonological and lexical access for words may be sequential processes which become automatic as a result of overlearning. However, for pictures, naming or phonological access requires

additional processing subsequent to semantic analysis. Indeed, the naming of pictures does not seem to be automatic. Pictures are better as search cues, accessing the memory representation; while words are better as response items, accessing the phonological codes. In the main, this evidence is consistent with Nelson's sensory-semantic model of picture and word processing.

ERPs and Mental Chronometry

Psychophysiological techniques, such as event-related potential (ERP) recordings of brain activity, have proven to be useful tools for accessing mental events which are not amenable to behavioural measurement. This section briefly describes event-related potentials and how they are measured and named. In addition it reviews the use of ERPs in studies of word and picture processing, and the implications of the endogenous waves for the study of memory processes.

Event-Related Potentials: Definition, Description and Nomenclature

The ERP reflects changes in electrical activity which occur in response to a physical stimulus or psychological event. This electrical potential which is time-locked to stimulus onset, is extracted from ongoing electroencephalographic (EEG) activity using signal averaging procedures. As the number of stimulus presentations increases, the random EEG noise tends to cancel itself out, while the signal (the ERP response to the stimulus) remains (see Campbell, 1985). Components of the ERP reflect the timing and quality of information processing. In general, the earlier the wave, the more likely it is generated by stimulus or sensory parameters such as its intensity, frequency, presentation rate or sensory modality. The longer the latency, the greater the dependence on "endogenous" or non-sensory

factors that are not directly related to physical stimulus characteristics. These factors include such cognitive processes as decision making, intention and signal value.

The ERP waveform consists of a complex series of peaks and troughs. Several methods of identifying these waves of the ERP are in common use. Each wave is characterized by its polarity, latency, scalp distribution, and function. A common method of labeling these waves is according to their polarity and peak latency. Polarity is either positive (P) or negative (N) and latency is measured in milliseconds. Thus, P300 is a positive peak occurring at 300 ms. The problem with this system of nomenclature is that the latency of a component may vary considerably depending on stimulus characteristics and task requirements. P300 can occur as early as 280 ms in easy tasks but as late as 750 ms in complex ones. P275 and P750 may therefore refer to components which share a common functional significance and scalp topography. To overcome this ambiguity, another alternative labels the waves sequentially. P300 is sometimes called P3 because it is usually the third large positive peak that is visible on the evoked potential plot. The problem here is that additional sub-components may also appear, dependent on specific task requirements. Thus, a component N1 may be divided into sub-components, N1a, N1b and N1c. The waves discussed in this paper are identified according to their peak latency. For example, P350 is a positive peak observed, in this study, at approximately 350 ms.

ERPs and Word Processing

As in the cognitive domain, the number of studies employing verbal stimuli far exceeds those investigating pictorial stimuli. Much of this interest in verbal processing has stemmed from an interest in identifying an asymmetrical

hemispheric dominance of language processes. The outcome of this research is equivocal. However, since much of our knowledge about the relationship of ERP waves to verbal and nonverbal processes is derived from this body of literature, a brief review is appropriate.

ERPs preceding speech are generally obtained by averaging backwards from voice onset. Some investigators have found greater activity over the left hemisphere than the right (McAdam & Whitaker, 1971; Low, Wana & Fox, 1973; 1979; Zimmerman & Knott, 1974; Levy, 1977; 1980; Pinsky & Adam, 1980). When artifactual potentials are however carefully controlled, many investigators fail to report hemispheric asymmetries (Morrell & Huntington, 1970; Grabow & Elliott, 1974; Szirtes & Vaughan, 1977; Brooker & Donald, 1980; Michaelowski, Weinberg & Patterson, 1977; Curry, Peters & Weinberg, 1978; House & Naitoh, 1979). Similarly, auditory ERPs to speech sounds display greater amplitude over the left than right hemisphere in some studies (eg. Morrell & Salamy, 1971; Matsumiya, Tagliasco, Lombroso & Goodglass, 1972; Neville, 1974; Molfese, 1977; Friedman, Simson, Ritter & Rapin, 1975a; Hillyard & Woods, 1979), while others report no differences (Haaland, 1974; Galambos, Smith, Schulman-Galambos & Osier, 1975; Tanguay, Taub, Doubleday & Clarkson, 1977; Genesee, Hamers, Lambert & Mononen, 1978; Hink, Hillyard & Benson, 1978; Grabow, Aronson, Offord, Rose & Greene, 1980).

Investigations of lateral specialization with visually presented words are similarly equivocal. Rugg and Beaumont (1978, 1979) presented letters and shapes, instructing subjects to make a discrimination based on phonological features or pattern. Although the lateral occipital P2-N2 wave was larger in response to the letters than the shapes, no hemispheric asymmetry was reported. Similarly, hemispheric symmetry has been found in a

variety of tasks including the processing of letter strings for their lexical and phonological attributes (Rugg, 1983), the sequential presentation of letters forming words (Shelburne, 1972) and the sequential presentation of words forming sentences (Friedman, Simson, Ritter & Rapin, 1975b). Rugg (1983) attributes this lack of lateral asymmetry to a bilateral involvement in the initial automatic decoding of letter strings. He suggests that this involves parallel visual and phonological processing. Thus, hemispheric ERP asymmetries may be more likely to occur during storage or further manipulations of the verbal material. In such tasks, the effects are again equivocal. Left greater than right asymmetries in the P1N1 range have been reported for the phonetic (Kana) compared to the ideographic (Kanji) Japanese script (Hink, Kaga & Suzuki, 1980). Similarly, Neville (1980) reported a substantial augmentation of N1 recorded over the left compared to the right parietal site for legible words than illegible degraded words. In a series of studies, Kutas and Hillyard (1980a,c; 1982) have found an asymmetry at 400-700 ms for words presented in meaningful sentences, but not when presented out of context. Overall, no clear consensus has been achieved from ERP studies of hemispheric asymmetries.

ERPs in Verbal Decision-Making Tasks

Considerable progress in the understanding of verbal processing has been achieved from an examination of the timing of linguistic processes. Several ERP waves, although they may not reflect processes uniquely related to language, are useful in assessing the time-course of language-related processes.

. P300 latency and mental chronometry. Perhaps the most extensively studied ERP component in cognitive paradigms is P300 or P3. This positive

endogenous component, is generally observed to be maximum at parietal sites, decreasing in amplitude at the central and frontal sites. This wave was first observed in a simple auditory task at approximately 300 ms. (Sutton, Braren, Zubin & John, 1965). Its latency is directly related to stimulus evaluation time, increasing in latency with increments in task complexity (Duncan-Johnson, 1981; Duncan-Johnson & Donchin, 1977; Johnson & Donchin, 1985; Kutas, McCarthy & Donchin, 1977; Pfefferbaum, Ford, Johnson, Wenegrat & Kopell, 1983). In contrast to behavioural measures such as reaction time (RT), P3 latency is relatively independent of response bias (Duncan-Johnson, 1981). Thus the latency of P3 can be used as an index of the time required to classify a target. Distinguishing stimulus evaluation processes from response selection processes is often difficult in RT paradigms (Campbell, 1985). When subjects were asked to determine whether words were similar phonologically, orthographically or both, P3 latency was longer when orthographic and phonological cues conflicted (Polich, McCarthy, Wang & Donchin, 1983). Thus, using ERPs, these investigators could conclude that interference occurred prior to response selection. Similarly, P3 latency has been used to differentiate stimulus from response processes in the Stroop colour-word task. In this case the interference caused by the colour name in reporting the colour of the word (eg. the word "yellow" printed in red ink) affected RT but not P3 latency. Thus, the Stroop interference effect was attributed to response incompatibility rather than interfering perceptual processes (Duncan-Johnson & Kopell, 1981).

P300 amplitude and word meaning. The amplitude of the P3 wave can also be used to index the information content of words in a sentence. Friedman and colleagues (1975b) reported that all words of a meaningful sentence

elicited P3s. The most informative words elicited the largest amplitude P3s. In particular, the final word of the sentence elicited large P3s, perhaps reflecting the property of syntactic closure.

N400 and contextual effects in language. ERP waveforms have been shown to reflect differences in meaning induced by changes in context (Brown et al., 1973). In a series of investigations, Kutas and Hillyard (1980a,b,c; 1982; 1983) demonstrated the sensitivity of a late negative wave, "N400", to the final word in a sentence when it was incongruous with the context built up by the rest of the sentence. The amplitude of the N400 wave was directly related to the degree of anomaly of the word. However, neither physical nor grammatical deviations had the same effect. When the ending of the sentence was appropriate they found a positive waveform, similar to the effect of syntactic closure described by Friedman et al. (1975b). Thus, support for separate syntactic and semantic analyses was found.

Further evidence of a relationship between N400 and contextual effects is found with tasks involving lexical or semantic categorization. When words or non-words were preceded by associatively related or unrelated primes, a late negative wave (340ms) increased in amplitude with decreases in semantic association. Moreover, words that are judged as not belonging to a semantic category, but not those which were judged as belonging, elicited N400s (Boddy, 1981, Boddy & Weinberg, 1981; Neville, Kutas & Schmidt, 1982; Polich, Vanasse & Donchin, 1981). Kutas and Hillyard (1984) varied the cloze probability of the final word in grammatically and syntactically correct sentences. N400 amplitude was again inversely related to the probability of the terminal word. They concluded that N400 was an index of the extent to which a word's representation was primed in the mental lexicon. Each

sequential word in the sentence seems to activate a set of probable subsequent words. The amplitude of N400 is larger the more improbable the ending.

ERPs to Pictures

There is a paucity of ERP studies employing pictorial stimuli. Those which have been reported can be classified into two types: shapes and patterns without meaning and meaningful drawings, photographs or paintings.

Meaningless shapes and patterns. A late fronto-central positive wave has been described in adults in studies which employ complex novel "splotches" (similar to abstract paintings) as stimuli (Courchesne et al., 1975). Unfamiliar shapes also elicit a series of late positive waves, which have been called P3, P4 and slow wave (Kok & deJong, 1980). All of these waves decreased in amplitude with stimulus repetition. The early P3 in these situations appeared to be a sign of preliminary categorization of the stimulus (eg. as deviant), while the late slow wave indicated the categorization of finer stimulus qualities (Kok & deJong, 1980).

Meaningful pictures. Although the waves elicited by verbal stimuli seemed to vary as a function of task requirements, stimuli such as meaningful pictures, which are inherently complex and interesting, may elicit late positive waves even when no specific task is defined. A P3-like wave is elicited by recognizable pictures of persons, paintings, and places, when subjects are instructed only to look passively at them. Thus, long-term memory of familiar pictures may be reflected in this type of P3. Pictures of faces with varying emotional salience evoke a series of positivities similar to those described above, P3 (latency, 300 ms), P4 (at 540 ms) and a slow wave (maximal at 920 ms) (Johnson, Miller & Bursleson, 1986). In this case,

the authors suggest that P3 and P4 are regulated by the emotional salience of the stimuli, and reflect the activation of memory storage mechanisms.

ERPs and Memory Processes

Several waves of the ERP waveform are useful indices of memory processing. Specifically, increases in amplitude (Karis, Fabiani & Donchin, 1984; Sandquist, Rohrbaugh, Syndulko & Lindsley, 1980) and decreases in latency (Johnson, Pfefferbaum & Kopell, 1985) of two late positive waves, P3 and a still later frontally positive slow wave (SW), appear relevant to memory performance. In addition, a negative wave, N400, increases in amplitude as the number of items to be searched in memory storage increases (Stuss, Picton & Cerri, 1986).

P3. Memory processes have most consistently been associated with the P300, or P3 wave. Johnson and his colleagues (1985) have recently reported a relationship between P3 latency and successful memory performance. Subjects were presented with a list of 75 words to be memorized (targets). They were subsequently asked to recognize those targets among distractor words (not previously presented). Study and test lists were repeated four times. Separate averages were obtained for targets and distractors. Targets elicited shorter latency P3s than distractors during the test phase (approximately 660 versus 710 ms for the initial test list). This difference was attributed to a priming effect which may have reduced stimulus evaluation time for target words on second presentation. P3 amplitude increased directly with repetition of the test for both targets and distractors. However, P3 amplitude was larger for targets than distractors only after the first presentation of the list. P3s from the study series were smaller than during the test series, and the latency did not vary with practice at acquisition.

When study trials were sorted according to recognition performance, subsequently recognized words elicited P3s which were approximately 22 ms earlier than those elicited by subsequently unrecognized words. P3 amplitude did not predict recognition performance.

A relationship between P3 amplitude and memory performance is observed with some consistency in ERP studies. In investigations of immediate recognition memory, such as delayed letter-matching and Sternberg paradigms, larger amplitude P3s have been reported to items which match the target or target set, compared to items which do not match the target (Thatcher, 1977; Posner, Klein, Summers & Budgie, 1973; Gomer, Spicuzza & O'Donnell, 1976). In general, large amplitude P3s are evoked in response to novel or unexpected events which are relevant to the task in which the subject is engaged (Campbell, Courschene, Picton & Squires, 1979; Duncan-Johnson & Donchin, 1977; Johnson & Donchin, 1980, 1982; Tueting & Sutton, 1976; Tueting, Sutton & Zubin, 1970). Donchin and his colleagues (Donchin, 1981; Fabiani, Karis & Donchin, 1985; Karis, Fabiani & Donchin, 1984; Klein, Coles & Donchin, 1984) argue that such events require the updating or revision of working memory, and that P3 reflects this updating. In their view, the updating process is required in order to revise the current schema of the environment. The amplitude of P3 is assumed to be directly proportional to the degree of revision of working memory. The memory representation or some attribute of that representation may be "activated" by this updating process and thereby facilitate subsequent recall of the event. The greater the restructuring associated with the event, the greater the likelihood that the event will be recalled. Accordingly, the amplitude of P3 during acquisition or learning of stimuli should predict subsequent recall. Karis, Fabiani and Donchin (1984)

examined this hypothesis using an "isolation" or "von Restorff" paradigm. The von Restorff effect describes the phenomenon that items which are very different from other items, or "stand out" are better remembered. Lists of 15 unrelated words were followed by a free recall task. Seventy-five percent of the lists contained one word which differed in size from the other words in the list. Following a recall test of these lists, subjects were asked to report the use of mnemonic strategies, and ERP waveforms were sorted on this basis. Two groups were defined, those who relied on simple repetition of the stimuli ("rote" memorizers) and those who formed more complex stories or images to organize the material ("elaborators"). The elaborators performed better on the test of recall than the rote memorizers. The type of mnemonic strategy reported was not only related to subsequent recall, but also to the occurrence of the von Restorff effect and the relationship between P3 amplitude and recall. Rote memorizers recalled fewer stimuli and obtained larger von Restorff effects than elaborators (subjects who used more complex strategies such as imagery or forming short stories). However, the P3 amplitudes elicited by the isolated words at acquisition did not differentiate rote memorizers and elaborators. These results were taken as an indication that the initial change in representation at acquisition was similar for the two groups. During recall, however, the rote memorizers may have relied primarily on the activation of the representation as a search cue, whereas the elaborators likely used associations formed during recall as search cues rendering the activation itself unbeneficial. In addition, the rote memorizer exhibited a direct relationship between P3 amplitude and recall. This effect was not obtained by the elaborators. Although this study did not control strategy use, a subsequent study did manipulate the

subjects' use of strategy experimentally, and obtained comparable results (Fabiani et al., 1985). A further investigation (Fabiani, Karis & Donchin, 1986) employed an incidental memory paradigm in order to reduce the use of rehearsal strategies. Subjects were asked to count either the male or female names in a series. Unexpectedly, they were later requested to recall as many names as possible. Larger P3s were obtained for names subsequently recalled than not recalled, again pointing to a direct relationship between P3 amplitude and recall for non-elaborators.

N400. A negative wave, occurring at approximately 400 ms is elicited primarily in linguistic tasks (Kutas & van Petten, in press), when a word embedded in a sentence is semantically incongruent (Kutas & Hillyard, 1980a, b), when arguments within a sentence are false or contradictory (Fischler, Bloom, Childers, Roucas & Parry, 1983), when a word from an infrequent or deviant category is presented in a discrimination task (Boddy & Weinberg, 1981; Polich, McCarthy, Wang & Donchin, 1983; Ritter, Ford, Gaillard, Harter, Kutas, Naatanen, Polich, Renault & Rohrbaugh, 1983) and when a word or picture is named (Stuss, Sarazin, Leech, & Picton, 1983; Stuss, Leech, Sarazin & Picton, 1984). In phonological matching tasks, non-rhyming stimuli elicit greater negativity around 400 ms than do rhyming stimuli, whether the stimuli are real words (Rugg, 1984a) or non-words (Rugg, 1984b).

In an attempt to dissociate the processes of P3 and N400 with respect to memory, Stuss et al. (1986) manipulated both stimulus probability and the number of target stimuli (pictures) in a naming task. They observed that the negativity in the 300 to 500 ms latency range increased as a function of increasing target set size from 1 to 5 to 20. Similarly, Mulder, Brookhuis, Okita, Van Dellen & Mulder (1984) reported a decrease in the P3 amplitude as

the memory set in a Sternberg paradigm increased. Both authors suggest that overlapping P3 and N400 waves are occurring. Stuss and his colleagues (1986) suggest that P3 reflects the updating of category-expectancies. The N400 may represent the activation of or activity of the memory search required in order to identify the stimulus. These two processes appear to be generated simultaneously.

Although some have argued that the N400 reflects a uniquely linguistic process (Kutas & van Petten, in press), reports indicating that mental rotation of geometrical shapes can also elicit a similar waveform (Stuss et al., 1984) weakens this argument. The most encompassing tentative explanation appears to include the broader involvement of memory representation activation.

Slow wave. The amplitude of a late positive SW has also been related to memory functioning. A SW at 800 ms is of greater amplitude for semantic and phonemic judgments than orthographic judgments, and predicted subsequent recognition in a memory task (Sandquist et al., 1980). Unlike P300, this SW predicted recall for those subjects employing elaborative operations on the stimulus (Karis, Fabiani & Donchin, 1984; Fabiani, Karis & Donchin, 1985). Several studies have indicated a relationship between SW and requirements for additional controlled processing of stimuli (Kok & deJong, 1980; Stuss et al., 1978, 1980; Johnson, 1979).

ERPs and the Picture Superiority Effect

Since ERPs can be used as indices of the timing and quality of mental processes, they should be helpful in identifying the stage or stages of processing which mediate the relative differences in recognition accuracy between pictures and words. The studies presented employ picture and word

stimuli in two versions of a recognition memory paradigm. These studies represent the first attempt at applying ERP methodology to issues of pictorial recognition memory. The hypotheses are therefore tentative and represent an exploratory look at the utility of ERPs in addressing these issues. Experiment 1 resembles the study-test procedure used by Johnson et al. (1985). Subjects were shown either picture or word stimuli. Independent groups were employed in order to overcome order effects. Pictures and words were matched for meaning. A series of small pilot studies were run to establish optimal recording conditions and to overcome problems of artifact. This investigation was performed in order to establish a time-course for picture-word processing differences in this task. This initial recognition memory paradigm also served to establish the conditions under which ERPs are recorded optimally in both acquisition and recognition phases of the task.

In Experiment 2, subjects were shown an equal number of randomly presented pictures and words during the acquisition task. They were asked either to remember the pictures, and ignore the words, or to remember the words and ignore the pictures. Subsequently they were either tested on the stimulus they had been asked to remember (intentional conditions) or the stimulus they had been asked to ignore (incidental conditions). Since intentionally learned stimuli are remembered better than incidentally learned stimuli to which relatively little attention has been devoted, this manipulation allowed us to examine within-stimulus variation in memory accuracy, as well as effects due to encoding strategies, which should be absent in the incidental condition.

Methodological and theoretical issues

Reaction Time

Cognitive psychologists have developed some very elaborate and elegant designs for examining processes not under their direct observation. A large proportion of the tasks implemented in experimental cognitive psychology measure human information processing through reaction time (RT). A number of subjective variables such as guessing strategies and response biases can markedly affect RT (Campbell, 1985). Several elaborate mathematical derivations of RT have been developed that take these factors into account. Formulae can correct for perceived relative costs of speed versus accuracy (Pachella, 1974), guessing (Link, 1982), the adjustments of response threshold which occur from moment to moment in comparing a memory representation with an external stimulus (Link & Heath, 1975; Link, 1975), and stimulus probability (Lappin & Disch, 1972). These mathematical controls aid in siphoning factors which may be inherent in the empirical situation, and emphasize the importance of such variables as instructional set, individual differences and the analysis of error trials (see Link & Heath, 1975; Link, 1975). The validity of many of these "correction" formulae has been questioned. Moreover, even if their validity is accepted, their proper application often requires several hundred, if not thousands, of trials. The processes or combination of processes which result in lengthened or shortened RTs remain "blurred" functions of underlying mechanisms, for which only the behavioural result is observed. It has been stated that ultimately the true answers of memorial representational structure and form will not be known until physiological evidence is obtained (Anderson, 1978). As already mentioned, the latency of the physiological measure, P3, appears to overcome many of the methodological limitations of the behavioural measure, RT. Unfortunately, very few memory studies have recorded concomitant behavioural

and physiological measures. The studies presented here represent a preliminary step to this end. The characteristics of the event-related potential, as discussed below, offer the capability of accessing "real-time" cognitive-related brain activity while it is ongoing.

Recognition memory tasks

The most well-known and striking differences in picture and word processing have been reported in tasks of recognition memory. Recognition memory for picture stimuli is extremely accurate, durable and extensive compared to that of verbal stimuli. However, the processes involved in recognition memory tests have historically been a subject of debate. One account presumes that since the target stimulus is presented to the subject in a recognition task, search or retrieval is not performed (Kintsch, 1970; Norman, 1968). The recognition task in this case involves a decision of familiarity with the stimulus. That is, a judgment is made regarding whether a stimulus appeared in the designated list or context. These theories readily explain why recognition tends to lead to superior memory performance than recall. Failure to recall is attributed to faulty memory search. In contrast, it has been proposed that recall and recognition involve basically similar processes (Tulving, 1976; Brown, 1976). In this view, the memory trace of an item depends on the similarity of this context-unique trace with the cues provided at retrieval. Recognition cues generally provide this overlapping information to a greater extent than recall. Hence a memory search is implied in the recognition task. Recent evidence seems to favour a combination of these two approaches: "Support has been adduced for the notion that the recognition of previous occurrence is adequately captured by a theory that assumes that two processes are invoked when someone is asked to

make a judgment of prior occurrence. The first process retrieves that familiarity value of the event ... The second, slower mechanism engages in a search and retrieval process that attempts to determine whether the target item was originally presented" (Mandler, 1980, p 268).

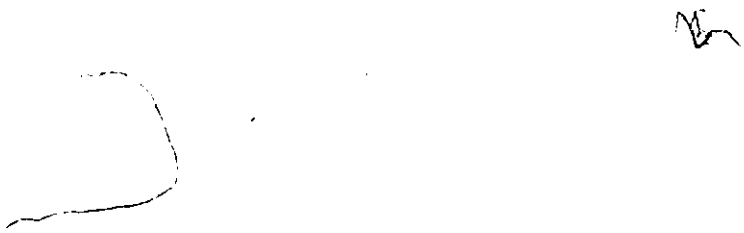
One of the weaknesses of recognition memory designs in the cognitive psychology literature, is that behavioural performance on the recognition test is often the only measure available for both encoding and retrieval processes, and the two processes are difficult to investigate independently. Using psychophysiological techniques, an invaluable amount of information both about the recognition memory task itself, and about recognition memory for different types of stimuli is potentially available.

Incidental learning paradigms

Generally, intentional learning results in superior memory performance than incidental learning. Nevertheless, this result depends on a number of factors, including whether an orienting task accompanies incidental learning (Gleitman & Gillett, 1957; Saltzman, 1953), the nature of the orienting task, (Postman & Adams, 1956; Saltzman, 1956; Craik & Lockhart, 1972, Craik, 1973; Craik & Tulving, 1975), the number of stimulus presentations (Gleitman & Gillet, 1957; Saltzman & Atkinson, 1954) and the manner in which learning is tested (Postman et al., 1955). Intention to learn is only effective insofar as it generates operations to improve memory performance. Subjects who report not using a memory strategy in intentional learning situations do not recall more than incidental learners who are asked to categorize words as nouns or verbs, and recognition performance is superior for this incidental learning group (Eagle & Leiter, 1964). The worst performance for incidental learning groups occurs when the orienting task requires the subject merely to

detect the presence or absence of a word. Thus it is the nature of the processing required during incidental learning that determines memory, not intention per se.

In the second study in this thesis, an incidental learning paradigm is used in order to examine within-stimulus changes in memory accuracy and associated changes in endogenous waves of the ERP waveform. The four resulting groups: incidental learning of words, intentional learning of words, incidental learning of pictures, and intentional learning of pictures, allow an examination of within-stimulus ERP changes which occur both at acquisition and recognition. During acquisition, the processing differences which are associated with incidental versus intentional learning are expected to be reflected in the ERP waveform. Such a relationship will provide insight into the portion (or portions) of the acquisition waveform that are associated with improved recognition performance for each stimulus. Similarly, during the recognition memory test, the comparison of relatively poorly encoded compared to relatively well encoded stimuli, should indicate which portion of the ERP waveform is associated with difficulty of memory search processes. Once these within-stimulus endogenous changes are identified, then across-stimulus comparisons can be made. That is, once the question "How is the ERP affected by this cognitive manipulation?" is answered, then the question "Is the ERP affected for both pictures and words in a similar manner?" can be tackled. If the series of waveforms in each case have the same latency and scalp topography, and are affected in the same direction, with similar magnitudes of change, then the processing of the pictorial and verbal stimuli will be considered similar. If, on the other hand, any of these variables differ, there is evidence for form-specific



processing.

Examination of Hypotheses

Conclusions about differences in processing for pictures and words and how these relate to memory performance differences are made on the basis of converging operations. First we ask how the cognitive manipulations affect the ERP waveform within each stimulus. That is, which waves are affected by task differences (acquisition/recognition, incidental/ intentional), in what direction, and how does this information relate to what is already known about the waveforms. Next, given that these cognitive manipulations have had an effect on the endogenous components, how do these changes compare across stimuli? Are the same waveforms affected by these manipulations for pictures and words? Finally, given what we know about the processing of pictures and words from the cognitive literature, and what we know about the components of the ERP, how can we reconcile these results, and what can they tell us about the superiority of pictorial memory? Based on both the cognitive and physiological studies, the waveforms of pictures and words were expected to differ in the following manner.

Early waves: exogenous or endogenous effects?

Given that the quality of information derived from individual fixations appears to be different for pictures and words it would be expected that picture/word processing differences related to memory should be apparent in the ERP waveform at approximately 250-300 ms. Differentiating between effects which are due to physical rather than cognitive processing differences of pictures and words is particularly of issue at this early latency. The incidental learning paradigm suggested here, however, purports to address this problem through a set of converging operations. By

definition, an exogenous wave remains unvaried for a particular stimulus when cognitive manipulations are performed. Thus, if a cognitive manipulation affects the response to that stimulus, it can no longer be considered exclusively exogenous. The within-stimulus manipulations (acquisition/recognition; hit/correct rejection; intentional/incidental) allow a discrimination between exogenous and endogenous effects. If a waveform is affected by any of these manipulations, we may conclude that it is, at least in part, associated with an endogenous process. On the other hand, if a waveform differentiates between picture and word stimuli, but is not affected by any within-stimulus manipulations, the problem is more difficult. Either the waveform reflects exogenous activity, or form-specific cognitive processes are associated with each stimulus.

P3 and incidental learning

The acquisition series of the incidental learning paradigm is quite unique, in that the subject's task is not only to remember stimuli, but to select the stimuli to be remembered from those to be ignored. In this context, it resembles the familiar "odd-ball" paradigm often used in P3 research. A rather complex series of decisions is required. Since the selection of the target may be based on gross physical differences between pictures and words, such as their spatial distribution or area, the P3 associated with this type of evaluation might be expected to occur relatively early. On the other hand, finer discriminations performed on the to-be-remembered items may be associated with later positivities (Johnson, in press).

P3 and prediction of memory performance

As previously noted, some studies of ERPs and memory have reported a

positive relationship between P3 amplitude and subsequent verbal memory performance. If encoding and retrieval processes for pictures and words are similar, we would expect that the same waveform would be associated with memory performance for each stimulus. This relationship would be manifested in the studies presented in this thesis in three ways. First, since pictures are remembered better than words, the amplitude of P3 at acquisition is expected to be larger for pictures than words. Second, since intentionally learned stimuli (both pictures and words) are remembered better than incidentally learned stimuli, P3 for intentionally learned stimuli is expected to be larger than for incidentally learned stimuli at acquisition. Third, a positive correlation between the average amplitude of P3 for each subject, and the d' scores would be expected. Moreover, the relationship between P3 amplitude and subsequent memory appears to be stronger when strategy use is limited (Karis et al., 1984; Fabiani et al., 1985; Fabiani et al., 1986), thus, a correlation between P3 amplitude and d' is more likely for those subjects who incidentally learned stimuli rather than those who intentionally learned the stimuli.

P300 and decision making in the recognition memory task

Since the P3 may serve as an index of stimulus evaluation time and is associated with stimulus discriminability in signal detection paradigms, P300 latency should reflect the time required for the familiarity decision required in the recognition memory task. When the probability of each response is held constant, as it is in recognition memory tasks, the amplitude of P300 generally reflects the confidence of the decision (Kerkhof, 1982; Kerkhof & Uhlenbrock, 1981; Parasuraman & Beatty, 1980; Parasuraman, Richer & Beatty, 1982; Squires et al., 1973a, 1975a,b; Sutton, Ruchkin,

Munson & Hammer, 1982) and decision accuracy (Campbell, Courschesne, Picton & Squires, 1979; Hanson & Hillyard, 1984; Hillyard, Squires, Bauer & Lindsay, 1971; Ruchkin, Sutton, Kietzman & Silver, 1980; Ruchkin, Sutton & Stega, 1980). Thus, since hit decisions are generally made with more confidence than correct rejections, P3 amplitudes should be larger for hits than correct rejections, and larger when the stimuli have been intentionally learned than incidentally learned.

N400 and contextual effects of the recognition memory task

The test phase of the recognition memory paradigm consists of the presentation of a series of stimuli, half of which were previously presented. This previous presentation should activate or prime the representations of target stimuli, while the remaining novel stimuli are not primed. The amplitude of N400 is inversely related to priming. It should therefore occur in response to those stimuli which have not been previously presented, i.e. the distractors. Similarly, the amplitude of N400 in the test phase should be greater for those stimuli which have been learned incidentally than those learned intentionally, since incidental learning probably results in less activation of related representations than intentional learning. Therefore, during the recognition test, the novel, distractor stimuli should elicit larger N400s than the incidentally learned stimuli, which in turn should elicit larger N400s than the intentionally learned stimuli. If the memory representations for pictures are functionally the same as those for words, as suggested by Nelson and his colleagues, then this relationship of N400 to distractor stimuli should be similar for pictures and words. If the memory representations for pictures are functionally different from those for words, as postulated by Paivio, and the dual coding theorists, then this

relationship will not be common for pictures and words.

Slow wave and further processing

Several investigations using both picture and word stimuli have described a late slow wave which has rather vaguely been considered an indication of further or elaborative processing. Little is known about this waveform and it is difficult to make any precise predictions about the effect of these manipulations on the SW. Since the acquisition phase of the incidental learning paradigm is designed to permit early elimination of a set of stimuli from further processing, the SW should be less prominent, if not completely absent from the waveforms of the stimuli to be ignored compared to those to be remembered.

CHAPTER II

Experiment I

Method

Subjects

Sixteen right-handed university students (4 males, 12 females) from 19 to 35 years of age participated in this study. All reported normal or corrected-to-normal vision. None had previously seen the stimuli employed in this study.

Stimuli

The picture stimuli were photographic slides of unambiguous black line drawings derived from children's colouring books (Stelmack, Plouffe & Winogron, 1983). The word stimuli were photographic slides of horizontally presented words, appearing in black upper-case elite font. The words were the verbal labels corresponding to the picture stimuli.

Stimulus presentation

One carousel projector equipped with a tachistoscopic shutter projected stimulus slides onto a wall in the main laboratory. A second projector presented a clear slide between stimulus slide presentations. The tachistoscopic shutter and 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 would coincide with the onset of the clear intermediate slide. This method was employed to eliminate confounding VEPs generated by changes in light intensity at stimulus onset. An RCA video camera relayed the projected image to a 22 cm video monitor placed 1.5 m from the subject in a sound-attenuated chamber. The difference in luminance

between picture, word and interstimulus slides as measured by a Spectra Pritchard photometer was negligible. Pictorial stimuli, on average, subtended a horizontal visual angle of 5° , and a vertical visual angle of 3° . Verbal stimuli subtended an average horizontal visual angle of 4° and a vertical visual angle of 1° . Stimulus onset, which occurred every 5 s, was initiated by a Cromemco Z-2 microcomputer.

Procedure

The experiment followed a yes/no signal detection procedure (Green & Swets, 1966). In this method, the proportion of hits and false alarms (FAs) were used to obtain a measure of recognition accuracy (d') which is relatively free of response bias. The protocol consisted of two series of stimulus presentations: an acquisition series and a recognition series. In the acquisition series, each subject was shown 140 consecutive stimuli, and was asked to remember them. Half of the subjects saw the pictorial stimuli, the other half, the word stimuli. The sex of the subjects was counterbalanced across groups. Each subject was informed that a test for memory would follow.

The recognition memory task followed the acquisition phase after a ten minute rest period. Subjects were asked to discriminate 60 target (previously shown) stimuli from 60 distractor (not previously shown) stimuli. These stimuli were presented in a computer-generated Bernoulli random sequence. The subject was requested to press one button to indicate that a stimulus had been previously presented or a second button to indicate that the stimulus had not been previously presented. Hand of response was counterbalanced across groups. Subjects were required to respond within the 2 s duration of the stimulus. A pilot study indicated that the motor response

occurring during stimulus onset had no effect on the ERP waveform compared to when the response occurred after its offset.

EEG recording

The EEG was recorded using Beckman Ag/AgCl electrodes affixed to the scalp at Fz, Cz, Pz, Qz, according to the International 10/20 system, and at two lateral temporal locations that were located 75 % of the distance from Cz to T3 on the left ("LT"), and to T4 on the right ("RT") (cf. Rugg, 1984). This corresponds to "C5" and "C6" placements in the 10-20 system. Pilot studies indicated that the more commonly used reference site, the mastoid process, is, in fact, active for the visual stimuli employed in this study. The sternovertebral site was not active. For the purpose of the pilot study, the ankle was used as a reference. Each scalp electrode was referred to a balanced noncephalic sternovertebral site (Stephenson & Gibbs, 1951). The electroculograph (EOG) was recorded from electrodes placed on the lateral extremity of both 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. The skin was abraded with a sterile needle at each of the scalp and EOG electrode sites to minimize skin potential artifacts (Picton & Hillyard, 1972). 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 was selected as a compromise between reducing the possibility that a low frequency negative sustained potential might overlap and sum with the late components (Picton, Woods & Proulx, 1978) and the risk of attenuating the amplitude of

the late components. Analogue-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 during which a signal exceeded ± 100 μ V on either the EOG or Fz channel were rejected prior to averaging. Eye movements from the centre to the horizontal or vertical edge of the monitor were observed to exceed this ± 100 μ V limit in pilot runs. Trials were also rejected if the subject's response occurred outside of the sweep time (i.e. 1.5 s post-stimulus offset). The averaged data were stored on diskette for later off-line plotting and scoring.

ERP measurements

Three components of the evoked response waveform which were clearly evident for all subjects were identified and measured using a computer scoring algorithm. Latency windows were derived from the morphological and topographical characteristics of the grand averaged waveforms. The maximum positive deflection occurring between 280 and 450 ms from stimulus onset was termed P350. The latency for this component was determined at Pz where this peak was most prominent, and amplitudes for all EEG sites were measured at that latency. The maximum negative peak between 400 and 600 ms from stimulus onset was termed N500. Latency was measured at Fz where this peak was most prominent and amplitudes for all channels were measured at that latency. The maximum positive peak between 480 and 700 ms was called P600. Latency was measured at Pz and amplitudes were determined at that latency for all electrode sites. In addition to these three peaks, a late frontal positive slow wave (SW) which reversed in polarity at Pz and Oz, was observed at a latency from 750 to 1400 ms. The SW was divided into three subintervals:

SW1 (750-900 ms), SW2 (1000-1150 ms) and SW3 (1250-1400 ms). Within each of these subintervals the average voltage was calculated independently for each electrode site.

Results

In the statistical analysis of these data, the .05 confidence level was adopted for all statistical tests, unless noted otherwise. Conservative confidence levels were employed for comparisons which involved repeated measures (Geisser & Greenhouse, 1958).

Recognition memory performance

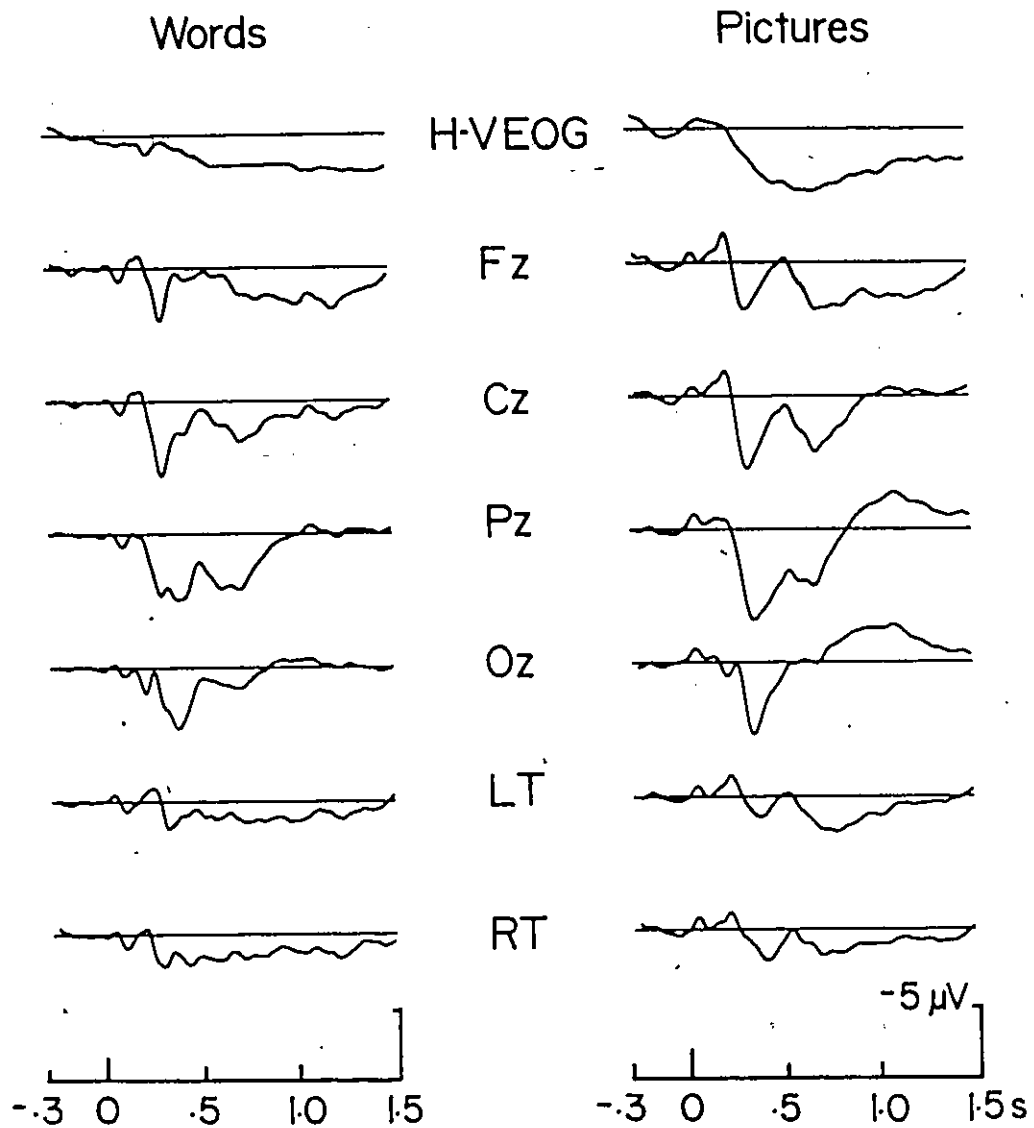
Discriminability indices (d') for recognition memory performance were calculated on the basis of the proportion of hits and FAs. A t-test performed on these data indicated that the mean recognition accuracy for pictures (2.69) was greater than that for words (1.56). The small number of misses and FAs for pictures precluded analysis of the ERP waveforms for those response categories.

Picture/word comparisons

Picture and word grand average waveforms for the acquisition phase are illustrated in Figure 2.1. P350 occurred at an average latency of 350 ms, N500 at 470 ms, and P600 at 585 ms. A one-way analysis of variance (ANOVA), pictures versus words, was applied to the ERP data obtained during the acquisition series, with an independent analysis performed for each component at each electrode site. Results from this analysis indicated that P350 was significantly greater for pictures than words at Pz ($F(1,14) = 4.9$). The amplitude of P600 was significantly greater for words than pictures during acquisition at Oz ($F(1,14) = 6.6$). However, at other electrode sites the amplitude of P600 was greater for pictures than words, although these did not

Figure 2.1 - Acquisition waveforms for words and pictures
in Exp I. In this and all other figures,
negative is up.

ACQUISITION

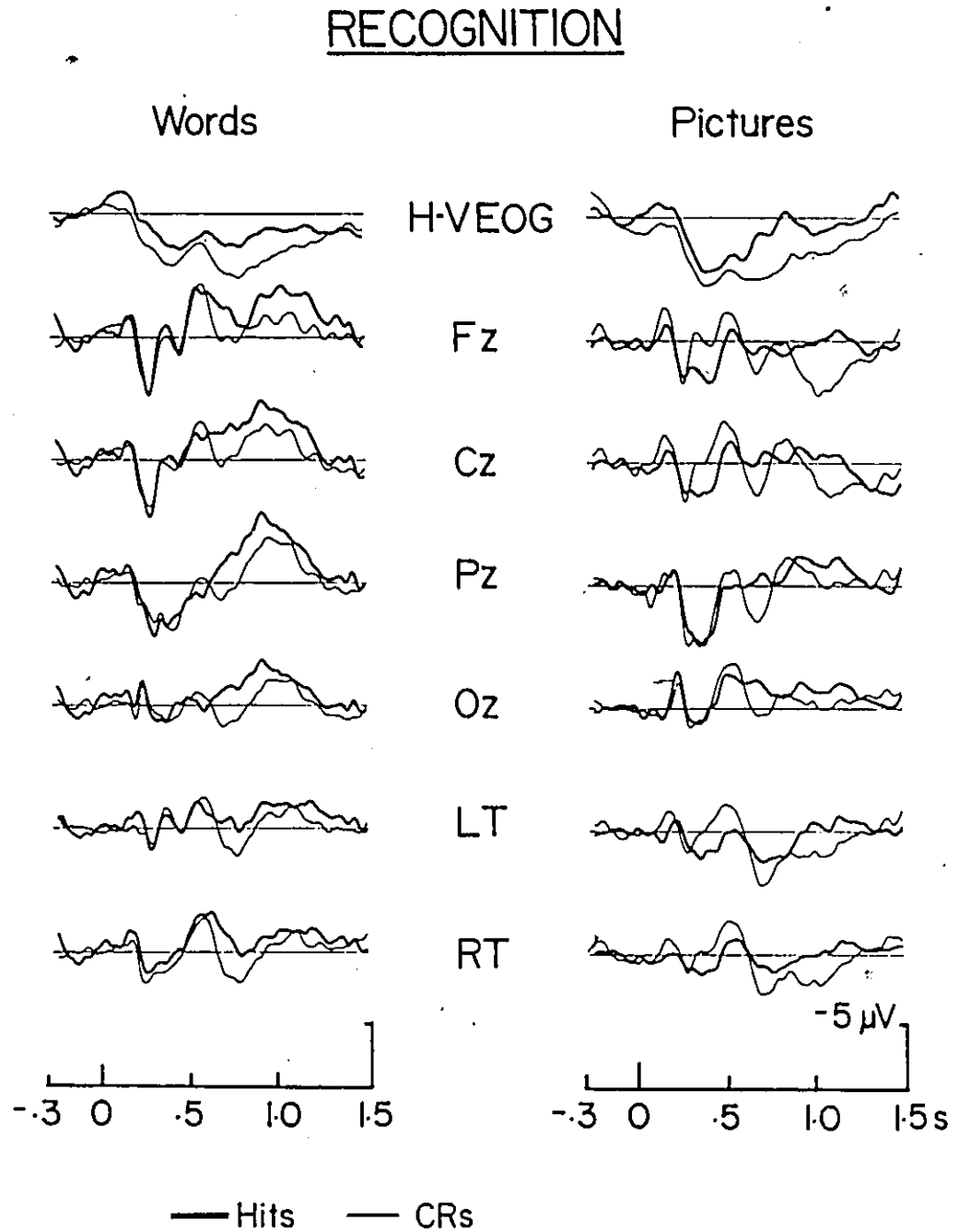


reach significance: Fz ($F(1,14)=2.2$; $p=.16$), Cz ($F(1,14)=2.2$; $p=.16$). No significant differences between the pictures and words were observed for the N500 component. The SW (750 - 1400 ms) was characterized by positive polarity at Fz and Cz, but negative polarity at Pz and Oz. This scalp distribution was observed in both picture and word waveforms. Significantly greater negative amplitude was observed at posterior sites for the picture than word waveforms at all three SW subintervals: SW1 at Oz ($F(1,14) = 15.3$), SW2 at Pz ($F(1,14) = 5.4$) and Oz ($F(1,14) = 18.6$) and SW3 at Oz ($F(1,14) = 5.8$).

It was also of interest to determine whether differences between pictures and words observed during the acquisition series were apparent during the recognition memory test. For this purpose, a two-way ANOVA with repeated measures was performed in the independent analysis of each ERP component at each electrode site. The between-subject factor was stimulus type (pictures and words) and the within-subject factor comprised the acquisition phase and the hit and CR categories of the recognition task. Unlike the one-way ANOVA performed on the acquisition data, P350 amplitude did not distinguish pictures and words at Pz when submitted to the two-way ANOVA. Since there were fewer hit and CR responses than there were stimulus presentations in the acquisition series, there were fewer evoked responses averaged for the former than the latter. As a result, there was a decrease in the signal-to-noise ratio, and an increase in the error variance in the two-way ANOVA which may have masked a P350 main effect or interaction.

Picture and word waveforms for hits and CRs are presented in Figure 2.2. Main effects of stimulus type were observed for two components. As in the

Figure 2.2 - Recognition waveforms for words and pictures in
Exp. 1



acquisition phase, the P600 component differed in scalp topography for the two stimuli. Across acquisition, hit and CR, P600 was significantly more positive for pictures than words at LT ($F(1,11)=4.6$). However, at Oz this P600 component was of greater amplitude for words than pictures ($F(1,14) = 6.6$). In addition, across acquisition, hit and CR waveforms, SW1 tended to be of greater amplitude for pictures than words at Fz (2.2 vs -0.4 uV, $F(1,11)=4.3$, $p = 0.06$), Cz (-0.03 vs -1.6 uV, $F(1,11)=4.2$, $p = 0.06$) and LT (1.45 vs -0.3 uV, $F(1,11)=4.3$, $p = 0.06$).

Acquisition/recognition comparisons. Reliable differences in ERP components of waveforms obtained during the acquisition and recognition memory test were also observed. These effects were common to both picture and word waveforms. Two components exhibited such effects, N500 and SW1. Grand averaged waveforms for hit and CR responses are superimposed in Figure 2.2. For both pictures and words, N500 amplitudes were greater for hit and CR responses during the recognition task than for acquisition waveforms at all electrode locations: Fz ($F(2,22) = 6.5$), Cz ($F(2,22) = 4.6$), Pz ($F(2,22) = 4.5$), Oz ($F(2,22) = 5.7$), LT ($F(2,22) = 5.2$) and RT ($F(2,22) = 14.9$). Also, for both stimuli, SW1 was significantly greater during the acquisition phase than for waveforms obtained from hit or CR responses during the recognition task at Cz ($F(2,22) = 4.9$) and Pz ($F(2,22) = 9.4$).

Discussion

In this study, differences between picture and word waveforms were observed primarily in the positive waves. At 360 ms (P350), 600 ms and during the late SW, pictures were associated with greater positivity than words. The retrieval process appeared to affect a common wave for pictures and words. For both stimuli, a negative wave at a 500 ms latency was larger in

CR waveforms than hit or acquisition waveforms.

Early components: endogenous or exogenous effects

P350 was observed to be larger in amplitude for pictures than words during the acquisition phase. We had expected that pictures and word waveforms would differ at approximately this latency based on the eye-movement/fixation studies. In this study it was possible that this difference could be explained by the physical difference between pictures and words. Memory for pictures has been said to stand "at the interface between perception and semantic memory" (Jolicoeur, Gluck & Kosslyn, 1984, p.244). That is, the perceptual qualities of pictures, and the information gleaned from them by 300 ms, appear to provide important information in the process of developing the memory representation. The incidental learning paradigm employed in Experiment II will shed light on this matter through a within-stimulus comparison of intent.

P3 and prediction of memory performance

Pictures and words were also differentiated by a second peak, P600, which exhibited the characteristic "P3" centro-parietal scalp distribution, with maximum amplitude at Pz and decreases in amplitude at the anterior and occipital sites. Late positive waves at this latency have been observed in several memory tasks (Johnson et al., 1985; Karis et al., 1984; Sandquist et al., 1980). In general, these studies report a positive relationship between P3 amplitude at acquisition and subsequent recall. In a recognition memory paradigm, using verbal stimuli, Johnson and colleagues (1985) also found large P3s at 600 ms during the acquisition series, even though all stimuli were equiprobable. However, in contrast to studies which have employed recall tests of memory, (Karis et al., 1984, Sandquist et al., 1980), Johnson

et al. (1985) found no P600 amplitude differences between subsequently recognized and subsequently unrecognized stimuli in their recognition memory task. Similarly, no midline amplitude differences between picture and word acquisition waveforms were found here. Our expectation that P600 would be of greater amplitude for pictures which are consistently better-remembered, had been based on recall studies, and thus was not confirmed. The memory tasks in which P600 amplitude differences have been found suggest that the type of strategy employed will determine whether P600 amplitude will be associated with memory performance. The second study includes a condition in which elaborative strategy use is discouraged.

The scalp topography of this wave appeared to be somewhat different for pictures and words. There was a tendency for P600 to be of larger amplitude for pictures than words at anterior sites. The opposite relationship was observed at the Oz lead. If this finding is replicated in the second study with a larger number of subjects, and an additional cognitive manipulation, it may be indicative of a difference in the underlying cerebral generation for pictures and words during the acquisition of items in memory.

N400 and contextual effects in the recognition memory task

The most striking difference between the acquisition and recognition memory waveforms for both pictures and words was a negative wave which occurred at approximately 500 ms. At all electrode locations this wave was of significantly greater amplitude during recognition than acquisition. Given that this wave is much more prominent in the recognition ERP, and since, in the case of targets, the stimuli themselves are identical to those presented in the acquisition phase, the process reflected by our

N500 is related to the requirements of the retrieval task, rather than an exogenous stimulus property. Initial pilot studies indicated that the enhanced negativity during the recognition task is not a result of motor potentials related to the button-press response. The finding that N500 is of greater amplitude in the recognition waveforms of both pictures and words is consistent with cognitive research indicating that the systems for retrieval of stored information are similar for pictures and words. The relationship between this wave and memory search is further investigated in Experiment 2.

Slow wave and further processing

A notable characteristic of the acquisition waveforms in this study was the appearance of a late slow wave (SW). SWs have been reported in tasks which involve feedback (Johnson & Donchin, 1985) or tasks which require "additional processing" following stimulus identification (Ruchkin, Sutton, Kietzman & Silver, 1980a; Ruchkin, Sutton & Stega, 1980b). The SW identified here was observed to have a remarkable polarity reversal, characterized by frontal positivity, which decreased in amplitude at Cz, and occipital negativity, which decreased in amplitude at Pz. This SW morphology was also apparent in the averages of individual subjects, and there was no indication that it resulted from overlapping P3s (cf Johnson & Donchin, 1985). The difference between picture and word waveforms at acquisition was largest and most persistent at Oz. At this site, significantly greater negativity was observed for pictures than words for all three measured durations of the SW. In view of the cognitive research which indicates quite clearly the greater involvement of visual and spatial information in encoding pictorial stimuli, this augmented activity at the occipital lead is particularly congenial. SW1

was of significantly greater amplitude for pictures than words at the fronto-central sites during both the acquisition and recognition tasks. However, the generally enhanced late negative amplitudes of the recognition waveforms seemed to obscure the picture-word differences at Oz.

As predicted, for both pictures and words, SW1 was of larger amplitude centro-parietally at acquisition than recognition. Generally, SWs have been reported to be indicators of extended processing (Karis et al., 1984; Ruchkin & Sutton, 1983; Sandquist et al., 1980). During the acquisition phase, extended processing in the form of elaborate strategizing is an effective means of accomplishing the task. In the recognition task, such processing is not required.

It is quite possible that the short time constant employed in this study affected the morphology of the SW. Although this limits the ability to compare the present SW to that of other investigators, the scalp topography and relative amplitudes involved in picture/word and acquisition/recognition comparisons would not be expected to be affected.

Summary

In summary, a review of the hypotheses indicates that this preliminary study was successful in outlining the time-course of picture-word processing differences. However, several questions regarding the quality or function of these processes remained. First, differences in the ERP waveform were observed at approximately 350 ms. Whether these differences were due to arousal or attentional differences between the stimuli or the physical characteristics of the stimuli could not be determined. Experiment II also examines within-stimulus changes in memory accuracy, and may therefore discriminate a purely exogenous wave from one which is clearly linked to

attentional and memorial events. The second investigation also questions whether earlier differences might not be observed, and measures a positive wave at 200 ms. Second, picture and word retrieval processes appeared to be similar, in that differences between acquisition and recognition were evident in the N500 peak for both stimuli. The second experiment alters encoding processes, and thereby the information available for retrieval. These within-stimulus differences in retrieval difficulty offers a further examination of this phenomenon. Third, to the extent that d' is inversely related to the extent of memory search invoked, N400 amplitude should be sensitive to manipulations which affect d' . N400 amplitude should be larger for words than pictures, and larger for incidentally learned stimuli than intentionally learned stimuli. Finally, the first study indicated that the SW was associated more with acquisition processes than recognition processes. If this wave reflects elaborative processes, it should be greater in the waveforms of the intentional learning condition for both stimuli, than the incidental condition, in which learning is discouraged.

CHAPTER III

Experiment II

MethodSubjects

Forty right-handed university students (20 male, 20 female) from 19 to 35 years of age participated in this study. All reported normal or corrected-to-normal vision. None had previously seen the stimuli employed in this study.

Stimuli and Stimulus presentation

The picture and word stimuli were produced and presented in the same manner as those in Experiment 1. The luminance and visual angle parameters also were the same as Experiment 1.

Procedure

The experiment followed a yes/no signal detection procedure (Green & Swets, 1966). In this method, the proportion of hits and false alarms (FAs) was used to obtain a measure of recognition accuracy (d'), which is relatively free of response bias. The protocol consisted of two series of stimulus presentations: an acquisition series and a recognition series. In the acquisition series, one of two sets of stimuli (Set A or Set B) was presented. Each set contained an equal number of randomly mixed word and picture stimuli to total 140. In order to counterbalance the denotative meaning of the stimuli, the words of Set B were the verbal labels corresponding to the pictures of Set A, and the pictures of Set B illustrated the word stimuli of Set A.

Half of the subjects ($N=20$) were asked to try to remember only the pictures, but disregard words, with the rationale that we were only

interested in seeing if the words interfered with remembering the pictures. They were told that they would later be tested on their memory for the pictures. Half of the subjects were told 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 task followed the acquisition phase after a ten minute rest period. Recognition of either the intentionally learned stimuli or the ignored stimuli was requested. Four comparison groups thus resulted: those who were asked to remember pictures and were subsequently tested on the pictures (intentional-picture group); those asked to learn the words and were tested on the words (intentional-word group); those asked to learn the words and were tested on the pictures (incidental-picture group) and those asked to learn the pictures, and were tested on the words (incidental-word group). Subjects were asked to discriminate 60 target (previously shown) stimuli from 60 distractor (not previously shown) stimuli, of the same type as the targets. These stimuli were presented in a computer-generated Bernoulli random sequence. The subject was requested to press one button to indicate that a stimulus had been previously presented or a second button to indicate that the stimulus had not been previously presented. The hand of response was counterbalanced across groups. Subjects were required to respond within the 2 s duration of the stimulus.

EEG recording

The EEG and EOG were recorded, amplified and averaged in the same manner as in Experiment 1.

ERP measurements

Four components of the evoked response waveform which were clearly evident for all subjects were identified and measured using a computer scoring algorithm. Latency windows were derived from the morphological and topographical characteristics of the grand averaged waveforms. The maximum positive deflection occurring between 220 and 280 ms was termed P200. The latency for this component was determined at Fz, where it was most prominent, and amplitudes for all EEG sites were measured at that latency. The remaining three components and the SW were measured at the same latencies and sites as those described in Experiment 1.

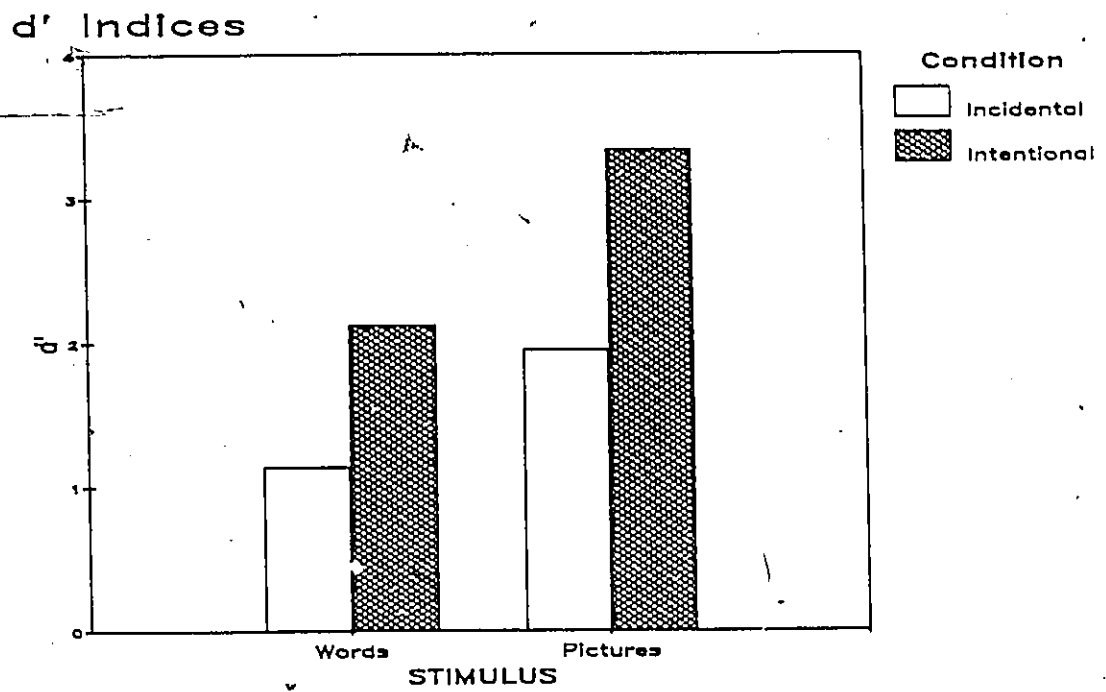
Results

Recognition memory performance

Discriminability indices (d') for recognition memory performance were calculated on the basis of the proportion of hits and false alarms (FAs). An ANOVA on these data revealed significant group differences. Mean d' values are illustrated in Figure 3.1. In order of superior to inferior performance, the groups ranked as follows: intentional-pictures ($d'=3.2$), intentional-words ($d'=2.2$), incidental pictures ($d'=1.8$) and incidental-words ($d'=1.3$). All group differences were significant with the exception of the incidental-pictures vs intentional-words comparison.

ERP waveforms

Four repeated-measures analyses of variance (ANOVAs) were performed per wave and electrode site. Since stimulus type (picture, word) was a within-subject factor at acquisition but a between subjects factor during the recognition task, the acquisition data were examined with a two-way repeated measures ANOVA, with stimulus as the repeated factor (both pictures and words were presented in the acquisition phase) and group (intentional learning of

Figure 3.1 - Mean d' scores obtained in Exp. II

words or intentional learning of pictures) as the second factor. ERP waveforms for the acquisition phase are presented in Figure 3.2. Recognition data were examined in a three-way repeated measures ANOVA (response type x stimulus x intention) with response type (hit, CR) as the repeated factor. Picture data were analyzed independently to compare acquisition with hit and CR response waveforms. The mean latencies and amplitudes of ERP waves for acquisition, hit and CR waveforms of intentionally and incidentally learned pictures are presented in Tables 3.1 and 3.2 respectively. A two-way ANOVA was employed, with acquisition, hit, CR as the repeated factor and intention as a between-subjects factor. Significant effects were investigated by post-hoc Tukey tests. An identical two-way ANOVA was employed for the word data. Mean latencies and amplitudes for intentionally and incidentally learned words are presented in Tables 3.3 and 3.4 respectively. Figures 3.3 and 3.4 show the ERP waveforms for hits and CRs respectively, for both stimuli. In addition, Pearson product moment correlation coefficients were obtained independently for each group, and for both acquisition and recognition waveforms between d' and the latency and amplitude of each wave. The Geisser & Greenhouse (1958) correction was applied and effects were considered significant at $p < .05$.

P200. The ANOVA performed on acquisition data indicated that the P200 wave was both of longer latency ($F(1,38)=8.91, p < .005$) for words ($X=249$ ms) than pictures ($X=241$ ms) and of larger amplitude for words than pictures at Cz ($F(1,38)=8.93, p < .005$), LT ($F(1,38)=14.03, p < .0005$) and RT ($F(1,38)=8.14, p < .006$). In addition, this ANOVA revealed an interaction between stimulus and intention at Fz ($F(1,38)=4.11, p < .05$). P200 was larger when pictures were to be remembered than ignored while no similar intentional/incidental

Figure 3.2 - Acquisition waveforms for words and pictures in Exp. II
EOG has been plotted at half gain.

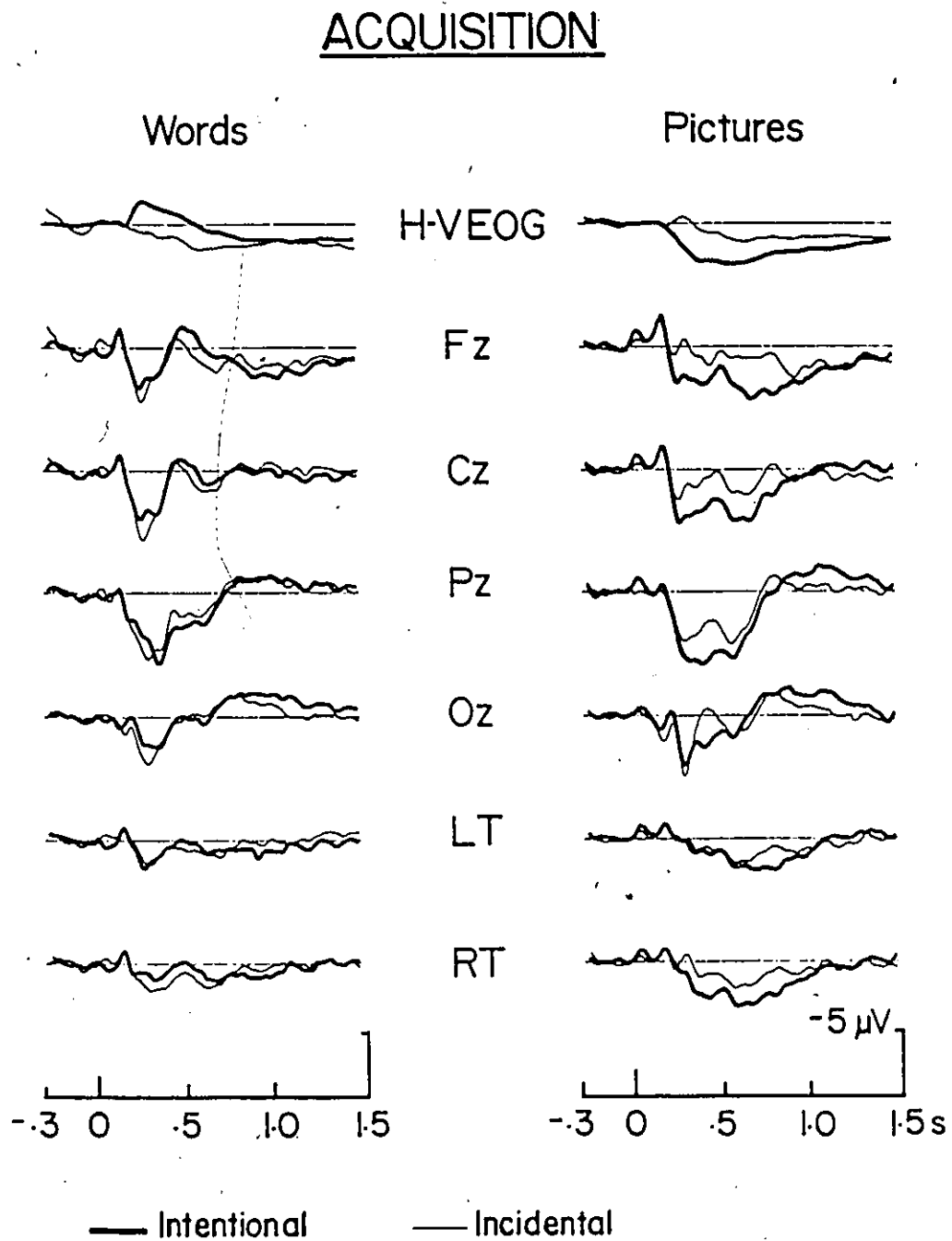


Figure 3.3 Hit waveforms for words and pictures in Exp. II
EOG is plotted at half gain.

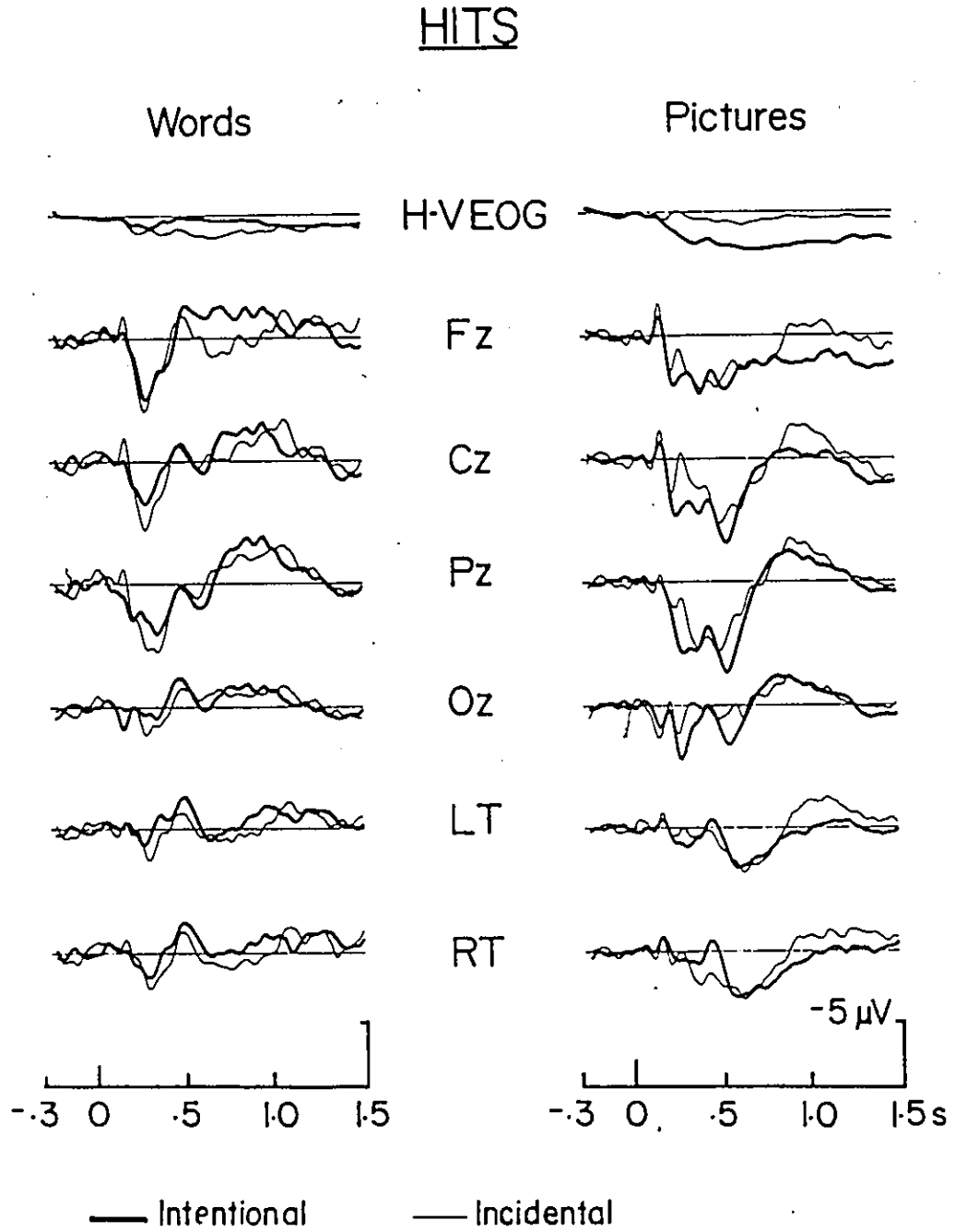


Figure 3.4 Correct rejection waveforms for picture and words in Exp. II. EOG has been plotted at half gain.

CORRECT REJECTIONS

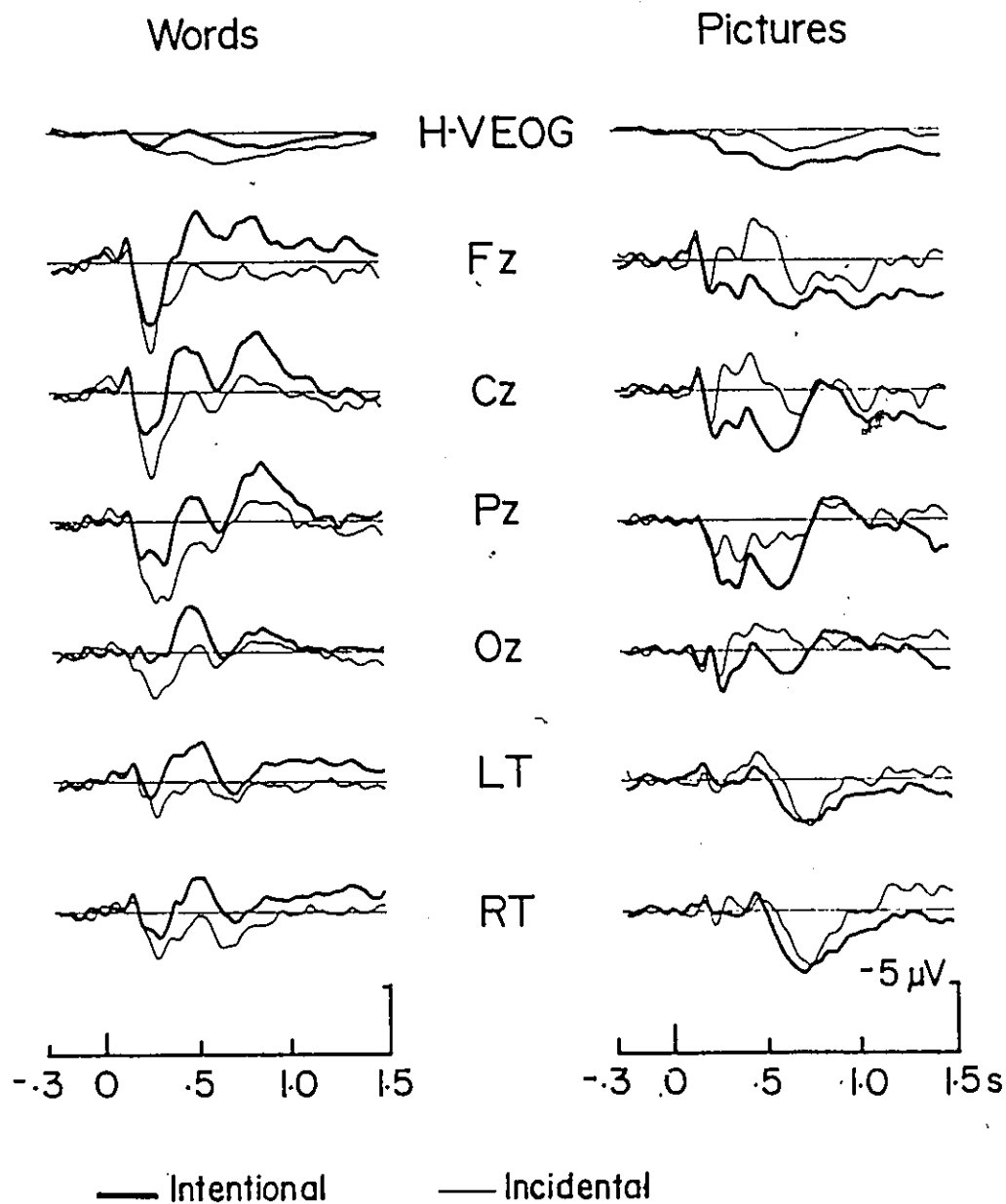


Table 3.1
 INTENTIONAL PICTURES CONDITION

Component	Latency	Electrode Site					
		Fz	Cz	Pz	Oz	LT	RT
ACQUISITION SERIES							
Pictures (Attended)							
P200	245	2.75	4.36	4.26	4.16	.43	.44
P350	340	4.99	5.71	4.67	4.18	2.96	3.43
N500	508	-.26	.62	.15	.95	.04	.65
P600	571	3.36	5.05	6.27	3.57	2.88	3.61
SW1	n/a	3.13	1.72	.05	-.86	2.22	2.34
SW2	n/a	2.43	.65	-.90	-.46	.96	1.01
SW3	n/a	2.08	.73	-.09	.32	.57	.94
Words (Ignored)							
P200	251	3.02	5.10	3.93	3.29	2.34	1.63
P350	348	2.21	3.32	7.03	2.75	1.87	1.68
N500	482	-2.61	-2.14	2.64	-1.02	-1.00	-1.61
P600	595	2.00	3.57	4.69	2.58	1.94	2.09
SW1	n/a	1.39	.41	-.55	-.66	.62	.76
SW2	n/a	1.49	-.08	-.92	-.85	.23	.38
SW3	n/a	1.02	.13	-.35	.03	-.12	.11
RECOGNITION SERIES							
Pictures (Hits)							
P200	244	4.16	4.48	5.64	4.42	2.53	1.43
P350	341	4.69	6.15	8.01	2.94	2.04	1.36
N500	505	-.22	1.23	2.11	-.04	.06	.17
P600	542	5.00	6.45	6.76	3.42	2.71	4.52
SW1	n/a	1.84	-.47	-2.04	-2.09	.72	1.09
SW2	n/a	1.38	-.40	-1.27	-1.05	-.36	-.10
SW3	n/a	2.26	1.61	.53	.72	.21	-.08
Pictures (Correct Rejections)							
P200	245	3.11	4.60	6.39	3.84	1.78	1.56
P350	322	2.74	4.34	7.69	3.49	1.51	1.72
N500	447	-1.06	.24	2.00	-.74	-2.18	-1.49
P600	561	4.69	6.88	7.12	3.17	3.25	4.81
SW1	n/a	2.23	-.21	-1.27	-1.15	2.06	2.90
SW2	n/a	3.11	2.05	.36	-.24	1.06	1.15
SW3	n/a	2.32	1.99	.75	.23	.53	.44

Table 3.2

INCIDENTAL PICTURES CONDITION

Component	Latency	Electrode Site					
		Fz	Cz	Pz	Oz	LT	RT
ACQUISITION SERIES							
Words (Attended)							
P200	251	5.66	5.40	3.93	2.39	3.79	1.44
P350	361	2.87	3.99	6.51	2.79	1.73	1.62
N500	490	-3.03	-2.20	1.48	.33	-.38	-.03
P600	580	2.94	4.47	5.86	2.01	2.81	3.66
SW1	n/a	2.10	.26	-.53	-1.35	.17	.71
SW2	n/a	2.18	-.11	-.54	-1.09	.37	.33
SW3	n/a	1.50	.62	.06	-.22	.08	-.18
Pictures (Ignored)							
P200	236	1.72	3.33	3.64	2.96	.63	-.47
P350	352	2.40	2.07	4.03	.88	1.72	1.86
N500	491	-1.84	-1.37	1.36	-1.00	-.81	.38
P600	548	3.43	4.21	6.40	2.76	3.75	5.06
SW1	n/a	1.88	.07	-1.16	-2.00	.96	.98
SW2	n/a	1.88	.71	-.04	-.34	.93	.55
SW3	n/a	1.68	.79	.30	.31	.33	.47
RECOGNITION SERIES							
Pictures (Hits)							
P200	238	2.51	.79	2.59	3.44	1.65	1.64
P350	340	5.55	4.13	7.53	2.50	1.51	4.44
N500	491	-1.60	.07	1.54	-.90	-.21	1.31
P600	577	5.86	7.10	5.59	2.31	4.87	5.58
SW1	n/a	.79	-1.12	-2.22	-1.72	.20	.38
SW2	n/a	-.85	-1.67	-1.82	-1.08	-2.07	-1.25
SW3	n/a	.34	.38	-.17	.09	-.75	-1.44
Pictures (Correct Rejections)							
P200	243	-.50	.02	2.77	2.34	.40	-1.02
P350	348	2.14	1.51	5.49	.89	.32	2.54
N500	473	-6.25	-4.96	-1.71	-3.95	-3.58	-3.00
P600	586	1.65	3.08	4.29	1.21	3.53	3.53
SW1	n/a	1.14	-.58	-.99	-.09	.99	1.56
SW2	n/a	1.42	.90	-.15	-.70	-.07	-.59
SW3	n/a	.14	.56	-.60	-.89	-.41	-1.41

Table 3.3

INTENTIONAL WORDS CONDITION

Component	Latency	Electrode Site					
		Fz	Cz	Pz	Oz	LT	RT
ACQUISITION SERIES							
Words (Attended)							
P200	247	4.05	5.20	5.02	4.04	2.34	1.55
P350	332	3.46	4.81	6.31	3.26	2.33	2.60
N500	492	-2.37	-1.97	-.14	-1.14	-1.14	-1.42
P600	523	1.89	1.98	3.07	1.09	2.16	1.10
SW1	n/a	-.11	-.63	-1.17	-1.28	.01	.18
SW2	n/a	1.32	.22	-.92	-.87	.14	.46
SW3	n/a	1.18	.53	-.67	-.45	.23	.14
Pictures (Ignored)							
P200	238	1.37	2.53	3.04	4.08	.29	.48
P350	327	2.42	3.26	4.68	2.29	1.79	2.22
N500	477	-2.31	-1.80	.12	-1.36	-.84	-1.01
P600	566	1.91	3.33	4.63	2.84	2.46	2.05
SW1	n/a	.56	.34	-.56	-1.09	.60	.51
SW2	n/a	.66	-.07	-1.01	-1.04	.27	.04
SW3	n/a	.21	.04	-.64	-.21	-.28	-.25
RECOGNITION SERIES							
Words (Hits)							
P200	239	7.01	5.34	3.89	1.02	1.60	2.99
P350	350	3.20	2.76	5.42	1.69	.13	1.30
N500	473	-4.74	-2.82	-1.09	-2.82	-3.65	-3.89
P600	575	.63	2.69	3.39	1.26	1.65	1.59
SW1	n/a	-1.88	-2.28	-3.39	-1.59	-1.00	-.56
SW2	n/a	-.68	-.77	-1.96	-.72	-1.05	-.81
SW3	n/a	-.47	.41	-.05	.29	-.92	-1.20
Words (Correct Rejections)							
P200	239	6.49	4.52	3.21	.90	1.32	2.67
P350	326	4.39	3.25	5.33	1.91	-.03	2.25
N500	488	-5.58	-3.60	-3.23	-4.18	-4.37	-3.00
P600	579	-.42	1.07	2.36	1.48	.87	.93
SW1	n/a	-2.76	-3.49	-3.29	-1.52	-1.44	-.82
SW2	n/a	-1.46	-1.07	-1.03	-.42	-1.72	-1.29
SW3	n/a	-1.49	.02	-.38	-.51	-1.50	-1.75

Table 3.4

INCIDENTAL WORDS CONDITION

Component	Latency	Electrode Site					
		Fz	Cz	Pz	Oz	LT	RT
ACQUISITION SERIES							
Pictures (Attended)							
P200	245	4.46	6.13	6.19	3.28	1.16	2.30
P350	368	3.99	4.73	7.62	3.05	1.60	3.61
N500	479	-.02	.65	2.65	-.30	-.33	.80
P600	543	3.11	4.73	6.20	1.87	2.62	3.18
SW1	n/a	3.10	1.38	-.66	-2.03	1.83	1.58
SW2	n/a	1.28	-.41	-2.27	-1.98	.08	.01
SW3	n/a	.53	-.33	-1.08	-1.50	-.66	-.45
Words (Ignored)							
P200	248	6.62	7.72	5.89	4.03	3.27	3.81
P350	314	4.63	5.42	6.97	3.91	2.64	3.69
N500	486	-2.34	-1.96	-.33	-1.00	-.40	-.06
P600	535	1.06	2.02	3.59	.99	1.89	2.23
SW1	n/a	.71	-.21	-.85	-1.22	.20	.25
SW2	n/a	1.34	.52	-.38	-.11	.32	.32
SW3	n/a	.90	.19	-.48	-.10	-.34	.12
RECOGNITION SERIES							
Words (Hits)							
P200	239	7.20	6.46	5.65	2.63	3.01	2.60
P350	322	3.95	4.46	6.73	3.23	2.14	3.49
N500	499	-5.23	-2.79	-1.43	-2.11	-2.19	-1.62
P600	560	3.93	3.71	3.62	1.37	2.50	2.41
SW1	n/a	1.24	-.92	-1.96	-.86	.78	1.11
SW2	n/a	-1.30	-2.29	-2.78	-1.46	-1.88	-1.72
SW3	n/a	-.55	-.20	-.33	-.01	-1.57	-1.62
Words (Correct Rejections)							
P200	238	8.41	7.40	6.84	3.84	3.85	3.95
P350	307	5.05	5.21	7.57	3.38	2.13	2.88
N500	487	-3.26	-2.56	-.19	-2.10	-2.78	-2.23
P600	562	3.60	4.29	4.98	3.06	3.35	4.14
SW1	n/a	1.41	-.31	-1.08	-.60	.38	.85
SW2	n/a	1.07	.63	.33	-.11	.13	-.25
SW3	n/a	.99	1.17	.94	.51	.17	-.14

difference was observed for the words.

The comparison of pictures and words for hit and correct rejection data also revealed a main effect of stimulus. P200 was of larger amplitude for words than pictures in the recognition response waveforms at Fz ($F(1,36)=10.01$, $p<.003$) and RT ($F(1,36)=4.9$, $p<.03$).

Neither the analysis of picture data across condition (acquisition, hit, CR) nor the analogous analysis of word data revealed significant effects.

P350. The P350 wave occurred at an average latency of 342 ms. The analysis of acquisition data revealed a significant interaction of group and stimulus type at Cz ($F(1,38)=6.95$, $p<.01$) and Pz ($F(1,38)=16.04$, $p<.0005$). P350 was larger for intentionally learned pictures than ignored pictures. However, no effect of intention for words was observed.

With respect to the analysis of hits and CRs for both stimuli, a stimulus by response category interaction was observed at Fz ($F(1,36)=4.43$, $p<.01$) and Cz ($F(1,36)=7.16$, $p<.05$). At these locations, P350 amplitude for pictures was significantly greater for hits than CRs, but for words no significant difference between response categories was observed.

The repeated-measures ANOVA performed across conditions (acquisition, hit CR) on picture waveforms only, revealed larger P300 amplitude for hits than acquisition waveforms at Fz ($F(2,36)=4.22$, $p<.05$), Cz ($F(2,36)=3.30$, $p<.05$) and Pz ($F(2,36)=5.43$, $p<.01$).

No differences between conditions were found in the repeated measures analysis of word data.

N500. The N500 wave occurred at an average latency of 485 ms. At acquisition, N500 was of greater amplitude for word than picture waveforms at Fz ($F(1,38)=6.78$, $p<.01$) and Cz ($F(1,38)=6.42$, $p<.02$), regardless of

intention. At Pz ($F(1,38)=5.52, p<.05$) and Oz ($F(1,38)=5.14, p<.05$) an effect of intention was observed only for pictures. Pictures to be remembered exhibited more positivity at this latency than pictures to be ignored. No similar effect of intention was observed for words in this analysis.

When hit and CR data were compared for the two stimuli, the N500 was larger for words than pictures at Pz ($F(1,36)=7.75, p<.01$) and LT ($F(1,36)=4.99, p<.05$). An interaction between response category and stimulus type was also observed, at Fz ($F(1,36)=5.61, p<.03$) and RT ($F(1,36)=5.16, p<.03$). For hits, N500 was of larger amplitude for words than pictures. For CRs, N500 amplitude was equally large for both stimuli. Also, a three-way interaction (response type x stimulus x intention) was observed at Fz ($F(1,36)=5.58, p<.03$) and Pz ($F(1,36)=7.03, p<.01$). For the CR waveforms, N400 was larger for the incidentally learned pictures than for the intentionally learned pictures. However, for words the reverse was observed, intentionally learned words exhibited larger N500s than incidentally learned words.

When picture data were analysed across conditions, larger amplitude N500 was found for CR than acquisition and hit responses at all electrode sites: Fz ($F(2,36)=6.69, p<.005$); Cz ($F(2,36)=6.6, p<.005$); Pz ($F(2,36)=4.01, p<.03$), Oz ($F(2,36)=5.62, p<.01$); LT ($F(2,36)=47.3, p<.01$) and RT ($F(2,36)=55.4, p<.001$). A similar analysis of the word waveforms revealed an effect in the same direction at Oz ($F(2,36)=3.74, p<.05$) and LT ($F(2,36)=6.35, p<.006$).

P600. P600 amplitude was larger for pictures than words during acquisition at Cz ($F(1,38)=5.4, p<.03$), Pz ($F(1,38)=14.2, p<.001$), Oz ($F($

1,38)=7.80, $p < .01$) and RT ($F(1,38)=8.35$, $p < .005$).

The analysis of hit and CR waveforms revealed a main effect of stimulus type in the same direction at Pz ($F(1,36)=5.08$) and RT ($F(1,36)=8.2$). A main effect of response type was also obtained. For both stimuli, P600 was larger for hits than CRs at Fz ($F(1,36)=5.2$, $p < .03$) and Cz ($F(1,36)=5.46$, $p < .03$). No interactions were significant.

SW1, SW2 and SW3. The scalp topography of the slow wave was characterized by a polarity reversal: fronto-central and temporal positivity, and parieto-occipital negativity.

During acquisition, SW1 was of greater amplitude for picture than word waveforms at Cz ($F(1,38)=6.38$, $p < .02$), LT ($F(1,38)=11.99$, $p < .001$), and RT ($F(1,36)=6.23$, $p < .01$).

During acquisition, SW2 was of greater (negative-going) amplitude for pictures than words at Oz ($F(1,38)=4.34$, $p < .05$). Independent analysis of picture waveforms revealed that SW2 was larger for acquisition and CR responses than hits at Fz ($F(2,36)=6.66$, $p < .002$), Cz ($F(2,36)=6.01$, $p < .006$), Pz ($F(2,36)=3.35$, $p < .05$), LT ($F(2,36)=10.87$, $p < .001$).

For both picture and word stimuli, SW3 was of greater amplitude for CRs than hits at Fz ($F(1,36)=6.16$, $p < .01$), Cz ($F(1,36)=13.39$, $p < .005$), Pz ($F(1,36)=12.75$, $p < .005$), Oz ($F(1,36)=4.05$, $p < .05$) and LT ($F(1,36)=7.81$, $p < .005$). In the analysis of picture data across conditions, SW3 was of larger amplitude for acquisition waveforms than hit and CR waveforms at RT ($F(2,36)=6.11$, $p < .01$).

Correlations

The correlations between acquisition waveforms and d' for pictures and words are presented in Table 3.5. At acquisition, the waveforms of words

Table 3.5

CORRELATION OF EP LATENCIES AND AMPLITUDES WITH d':
ACQUISITION SERIES

Component	Latency	Electrode Site					
		Fz	Cz	Pz	Oz	LT	RT
Words (Intentional, N=10)							
P200	-.03	-.33	-.35	-.24	.01	-.13	-.51
P350	.00	-.31	-.26	-.32	-.36	-.05	-.33
N500	.46	-.47	-.43	-.26	.00	.08	-.04
P600	-.37	-.20	-.48	-.40	.05	-.12	.08
SW1	n/a	-.06	-.18	.03	.04	.03	-.07
SW2	n/a	.30	.05	.05	-.18	.41	.05
SW3	n/a	.54	.13	-.31	-.35	.58	.23
Words (Incidental, N=10)							
P200	.35	-.01	-.26	-.10	-.28	.19	-.11
P350	.16	.29	-.17	-.44	-.59	.11	-.22
N500	.03	-.22	-.09	.02	-.32	-.11	-.51
P600	-.19	-.49	-.62*	-.59	-.62*	-.48	-.82*
SW1	n/a	-.46	-.36	-.39	-.34	-.32	-.45
SW2	n/a	-.58	-.44	-.40	-.23	-.46	-.52
SW3	n/a	-.17	-.11	-.12	.12	.01	-.01
Pictures (Intentional, N=10)							
P200	-.24	.19	-.00	.09	.08	.20	.05
P350	.54	.04	.42	.23	-.08	.02	-.09
N500	.80*	.21	.26	-.07	-.12	.30	-.28*
P600	.13	-.27	-.37	-.68*	-.74*	-.34	-.74*
SW1	n/a	.14	.38	.21	.19	.15	-.17
SW2	n/a	-.11	.02	-.12	.11	-.03	-.03
SW3	n/a	-.28	-.15	-.14	.07	-.11	-.29
Pictures (Incidental, N=10)							
P200	-.33	.07	-.32	-.66	-.65	-.70	-.36
P350	-.17	-.34	-.51	-.56	-.32	-.46	-.50
N500	-.08	.08	.12	.07	-.17	.06	.14
P600	-.21	.14	.22	.36	.18	.45	.50
SW1	n/a	.39	.33	.22	.04	.39	.26
SW2	n/a	-.02	-.14	-.23	-.27	-.12	-.15
SW3	n/a	-.14	-.29	-.38	-.23	-.19	-.23

which were intentionally learned and pictures incidentally learned were not significantly correlated with d' for any wave. However, for those subjects who incidentally learned words, d' was correlated negatively with P600 at Cz ($r=-.62$), Oz ($r=-.62$), and RT ($r=-.82$). For those subjects who intentionally learned pictures at acquisition, P600 was also negatively correlated with d' at Pz ($r=-.68$), Oz ($r=-.74$), and RT ($r=-.74$). In addition, for intentionally learned pictures, P300 amplitude at Fz was positively correlated ($r=.65$) with d' . N500 latency was also positively correlated with d' ($r=.80$) for this group. That is, subjects who had larger d' tended to have later N500s. Recognition waveforms were also observed to contain waves which were correlated with d' (see Table 3.6). In particular, increases in N500 amplitude for CRs were associated with decreases in d' . P600 amplitude was positively correlated with d' for this group.

Table 3.6

CORRELATION OF LATENCIES AND AMPLITUDES OF ERP COMPONENTS WITH d' :
RECOGNITION SERIES

Component	Latency	Electrode Site					
		Fz	Cz	Pz	Oz	LT	RT
PICTURES (INTENTIONALLY AND INCIDENTALLY LEARNED, N=20)							
Hit Responses							
P200	-.08	.09	.12	.13	.18	.02	-.08
P300	-.02	.04	.40	.04	.08	.02	-.29
N500	.25	.22	.27	.12	.32	.26	.07
P600	.16	.05	.02	-.06	.06	-.10	-.26
SW1	n/a	.34	.29	.28	.21	.24	.43
SW2	n/a	.31	.30	.22	.03	.44*	.29
SW3	n/a	.37	.49*	.30	.28	.44*	.41
Correct Rejection Responses							
P200	.04	.01	.03	.05	.01	.02	.04
P300	-.14	-.05	.29	.15	.26	.07	-.22
N500	-.22	.66*	.68*	.56*	.51*	.31	.25
P600	-.04	.54*	.53*	.52*	.34	.30	.35
SW1	n/a	.23	.19	.16	-.02	.25	.23
SW2	n/a	.16	.27	.29	.16	.30	.17
SW3	n/a	.32	.40	.46*	.34	.34	.42*
WORDS (INTENTIONALLY AND INCIDENTALLY LEARNED, N=20)							
Hit Responses							
P200	.01	.10	.05	.09	-.11	.39	.00
P300	.35	-.09	.12	.21	.18	.32	.46*
N500	.10	-.23	-.14	-.18	-.55*	-.23	-.14
P600	-.01	.00	.26	.31	.18	.21	.43
SW1	n/a	.00	.02	.18	.20	.20	.43
SW2	n/a	-.29	.45*	.49*	.27	.41	.40
SW3	n/a	.21	.45*	.49*	.27	.41	.40
Correct Rejection Responses							
P200	-.15	-.05	-.08	.03	-.03	.19	.13
P300	.22	-.18	-.09	-.03	-.07	-.16	.16
N500	-.10	-.28	-.17	-.08	-.05	-.18	-.07
P600	.12	-.16	-.15	-.21	-.21	-.05	-.11
SW1	n/a	.05	.04	.02	.12	.02	.14
SW2	n/a	-.01	.07	.14	.24	.10	.15
SW3	n/a	-.09	-.12	-.12	-.01	.00	-.05

CHAPTER IV

Discussion

This discussion is presented in three segments. The first examines within-stimulus effects of the cognitive manipulations. Specifically, it examines each stimulus (pictures/words) separately in determining which waves are affected by task differences (acquisition/recognition; incidental/intentional). In the second section, these effects are compared across stimuli. That is, the manner in which the experimental manipulations affected words compared to pictures is discussed. ERP waves for pictures and words are compared in terms of the hypotheses outlined in the first chapter. Finally, the third section discusses the implications of the electroencephalographic recordings for cognitive theories of picture and word processing.

Recognition memory for pictures was superior to that of words, and intentional learning led to superior memory performance than incidental learning, replicating previous reports (Cohen, 1974). These findings indicate that the instructional manipulation of remembering or ignoring a stimulus had the desired effect on the subject's recognition memory performance. All subjects in the incidental learning groups reported surprise when asked to recognize the incidentally learned stimuli.

Within-stimulus effects

Effects of Cognitive Manipulations on word ERPs. Previous investigations (Karis, Fabiani & Donchin, 1984; Fabiani et al., 1985, 1986; Karis & Donchin, 1985) had indicated that words which were later recalled could be distinguished from words which were not later recalled based on the acquisition waveforms. Since intentionally learned words are recognized more

successfully than incidentally learned words, we had expected that the waveforms of these groups might differ at acquisition. In particular, P600 amplitude was expected to be augmented for the intentionally learned words compared to the incidentally learned words. However, no significant differences were observed in the acquisition waveforms of the intentionally learned and ignored words. It could be argued that this hypothesis was not confirmed because the subjects were not following the instructions. This seems unlikely since the d' indicated significantly greater discriminability for the stimuli intentionally learned compared to those ignored. The instructions seem to have had the desired effect.

Although P600 amplitude did not differentiate between intentionally learned and ignored words, previous studies have reported a positive relationship between subsequent recall and the amplitude of a positive peak with a similar latency and scalp topography (Karis et al., 1984; Fabiani et al., 1985, 1986). Several methodological differences may account for such a discrepancy. The Karis et al. (1984) and Fabiani et al. (1985, 1986) studies employed oddball-type "von Restorff" paradigms. The Karis et al. study averaged waveforms based on a posteriori reports of mnemonic strategy use, while the Fabiani et al. (1985) investigation manipulated the subject's strategy. In these studies, their "P300" (similar in latency and topography to the present P600) amplitude per se did not reflect the recall difference between rote memorizers and elaborators at acquisition. Both investigations reported that the relationship between P300 and recall was a function of strategy use. For rote memorizers, P300 amplitude was associated with subsequent recall. When elaborative strategies were used, no relationship between P3 and recall performance was found. In explaining this

effect, the authors suggested that the initial change in the memory representation at acquisition is similar for rote memorizers and elaborators, and that the disparity in recall accuracy is a result of differences in processing occurring at retrieval. They thought that rote memorizers might rely on an activation of original representations while for elaborators a network of associations had been accessed. These studies may explain the lack of correlation between d' and P600 for intentionally learned words, since the use of mnemonic strategy in that condition was likely. However, our finding of a negative correlation between P600 amplitude and d' for incidentally learned words contrasts with the results of Fabiani and her colleagues (1986) in their incidental learning paradigm.

The use of recognition rather than recall paradigms also differentiate the results obtained in the studies presented here from previous investigations. The Karis et al. (1984) and Fabiani et al. (1985, 1986) studies all used a recall test of retrieval, while Johnson et al. (1985) and Stelmack, Saxe, Noldy-Cullum, Campbell & Armitage (in press) employed recognition memory paradigms. The investigations which used recall paradigms found that items which were later recalled exhibited larger amplitude P600s at acquisition. When recognition memory paradigms are employed, such a relationship is not observed. Johnson and his colleagues (1985) found no relationship between their P300 amplitude and subsequent recognition, while Stelmack et al. observed a negative correlation. Perhaps qualitative differences in the two paradigms can explain processing differences. Recognition generally leads to superior memory performance than recall. In a recognition task, the subject is given alternative responses, and uses them as cues in retrieval. The stimuli remembered in this type of task may be very

different from those remembered when no such cues are given. Indeed, recall and recognition have been described as independent processes (eg. Tulving & Thomson, 1973; Tulving, 1983). Thus, the type of memory performance that we are measuring, and relating back to encoding may be different.

Fabiani et al. (1986) have suggested that the relationship between P3 and verbal memory may be unique to situations in which intra-item integration rather than inter-item integration is more likely. Intra-item retrieval strategies, involve the formation of associations of items on the list with items in long-term memory, for instance, when items recollect events from the past. Inter-item associations are those formed between items in the list. This interpretation is consistent with the finding that those subjects who used elaborative semantically-based strategies exhibited neither a von Restorff effect nor a relationship between P3 and later recall (Karis, Fabiani & Donchin, 1984; Fabiani et al., 1985). It may be that the same relationship does not hold when the test of retrieval is a forced-choice recognition task.

The only difference between ERPs for intentionally learned and incidentally learned words was observed in the recognition waveforms. The N500 was larger for intentionally learned than incidentally learned words. Thus, the discrimination between the waveforms of subjects whose recognition accuracy was more successful compared to those who recognized fewer words, was not found in the acquisition, but in the recognition waveforms. This finding supports the contention that retrieval strategies might be just as important as encoding strategies, if not more important in determining performance in a recognition memory task (Tulving & Thompson, 1971, 1973). It also underlines the utility of information that can be gained by examining ERPs associated with retrieval as well as acquisition.

In addition, the correct rejection waveforms from the recognition test were distinguished from both the hit and acquisition waveforms by activity which began at approximately 500 ms, and continued to the end of the epoch. This effect can not be attributed to the presence of a motor readiness potential preceding the button press since N500 for hit responses, which required a motor response, was similar to that of acquisition waveforms, which did not require a physical response. The CR waveforms are characterized by a frontal negative shift in N500, while the hit tracings (particularly of intentionally learned stimuli) and acquisition waveforms are influenced by a parietal positivity at this latency. Kutas and Hillyard (1980c) have reported the tendency for N400 and P3 to overlap in latency. Some combination or weighting of the processes reflected by these waves may be responsible for the N500 effect. It appears that the process associated with the N500 is engaged to a greater extent during the recognition task when distractors are presented. Boddy (1986) reported a prolonged negativity which occurred when a priming stimulus was not semantically related to the target. He suggested that unexpected stimuli augment arousal and facilitate a switch from automatic to controlled processing. Augmented negativities in this latency range have also been reported when semantic expectancies built up by sentence context are violated (Kutas & Hillyard, 1980a, b, c, 1983). Since the target stimuli have been previously associated with the experimental context at acquisition, they are primed during the recognition task. Distractor stimuli are not so primed, thus evoking large N500s.

Effects of cognitive manipulations on picture ERPs. The ERPs elicited by pictorial stimuli were very similar to those described by V. Johnson et al. (1986). Two prominent positive peaks and a slow wave were observed in both

cases. V. Johnson reported that the amplitude of P3 (300 ms), and P4 (540 ms) were modulated by the emotional salience of the pictures. R. Johnson (in press) suggests that multiple P3s to complex stimuli involve an early P3 which is associated with complexity variables, while the later P3 is associated with classification of that information. Further, studies which compare P3 latency with RT indicate that stimulus categorization is not complete until the time of the second P3.

During the acquisition task the waveforms of the to-be-remembered pictures differed from those of the ignored pictures. In this task, the pictures seem to be classified very early as stimuli to-be-remembered (or -ignored). Increased positivity at 250 ms, 350 ms and 500 ms was associated with intention. It is not likely that even the earliest of these represent exogenous effects since, for pictures, the P200 was affected by the manipulation of intention. A possible explanation of this effect would be one of attention. At acquisition, the task requires a decision to remember a picture and ignore a word. Since the stimuli can be distinguished relatively rapidly based on physical form, the decision to attend might most expediently be made on this basis. Thus, the enhanced P200 for the to-be-remembered pictures compared to the to-be-ignored pictures might reflect such a decision process. However, selections among stimuli made on the basis of physical characteristics such as colour, spatial orientation and contour have been previously associated only with a broad negative wave at this latency (Harter & Salmon, 1972; Harter & Previc, 1978; Harter & Guido, 1980; Previc & Harter, 1982; Harter et al, 1982; Hillyard & Munte, 1984). In addition, attention-related waves in the visual modality are generally recorded with a posterior maximum (Eason et al., 1969; Van Voorhis & Hillyard, 1977; Eason,

1981; Harter et al., 1982; Hillyard and Munte, 1984). The P200 wave observed here was generally larger at more anterior locations.

An alternative explanation is that the P200 is analogous to the "P3a" described by several investigators. P3a occurs at a shorter latency (220 to 280 ms) and is more anteriorly distributed (Roth, 1973; Squires et al., 1975, 1977; Snyder and Hillyard, 1976; Ford et al., 1976) than the later parietal "P3b". The P3a generally responds to stimulus deviance regardless of task relevance, or the subject's level of attention and has thus been likened to the orienting response. This view is consistent with the larger amplitude P200 for pictures which are to-be-remembered compared to those which were to-be-ignored. The orienting response has been associated with subsequent memory performance (Stelmack, Plouffe & Winogron, 1983; Ohman, 1979), and therefore might explain the positive correlation between the amplitude of this wave and d' for intentionally learned pictures. However, no such correlation was observed between the amplitude of P200 for incidentally learned pictures and d' . Thus, the description of our P200 as a P3a for pictures is tenuous.

The augmented positivity associated with intention for P350 and N500 are perhaps more readily explainable. The pattern of effects associated with P350 indicate that it is likely a P3 (or P3b). P350 is distributed maximally in parieto-central sites similar to the oddball "P3". The task relevance of the intentionally learned stimuli, is similar to the targets in the oddball paradigm and might be expected to elicit a similar P3. The N500 wave for pictures at acquisition seemed to be overridden by a positive-going waveform. The overlapping of positive waves (400 to 500 ms latency) with N500 has been reported by Kutas and her colleagues, in tasks involving complex decisions. The relative positivity at approximately 500 ms observed here might also be an

effect of an overriding additional P3.

The recognition waveforms also distinguished the intentionally from incidentally learned pictures. N500 was greater for incidentally learned than intentionally learned pictures. The empirical support for a relationship between priming and N500 has been previously discussed. The explanation of this relationship in terms of memory search requirements is supported by our results. A larger N500 for incidentally learned pictures than intentionally learned pictures at recognition .

Consistent with investigations which have examined the relationship between P3 and signal detection (Squires, Squires & Hillyard, 1975a,b), and with effects observed in a verbal recognition memory experiment (Johnson, 1985), hits were associated with augmented positivity compared to CRs. Whether this effect occurs because of the increase in amplitude of the N400 at this latency for CRs, or because the hit responses are associated with augmented P3 amplitudes remains unclear.

A comparison of ERP effects for pictures and words

P200: exogenous or endogenous effects. The P200 was differentially sensitive to cognitive manipulations for words and pictures. None of the cognitive manipulations or changes examined reliably altered the latency or amplitude of the wave for the verbal stimuli, while the instruction to remember rather than ignore did alter the amplitude of this wave for the pictures in the acquisition waveforms. For intentionally learned pictures, P200 was larger than for incidentally learned pictures. This finding is consistent with the view that early processing (perhaps phonological or lexical) becomes automatic for words, while for pictures this is not the case. An automatic process would be expected to occur both during intentional and

incidental processing of a stimulus, while controlled processing is affected by intention and is more likely to be engaged under intentional than incidental conditions. Although this is not decisive evidence that automatic processing is reflected by this wave for words, our results are in the expected direction, and may indicate of form-specific processing at this early stage. Further investigations of the properties of automaticity and their relationship to this wave are required.

EOG activity is also apparent at this early latency. The EOG, like the activity at the frontal site is of greater amplitude for attended than ignored pictures at acquisition. It might be argued that the large frontal positivity was therefore not generated by intra-cerebral activity. It is an unfortunate reality that visual tasks of the type employed in this study will involve some degree of eye movement. Without correction procedures designed to remove the effects of eye movement on EEG activity, it may be impossible to dissociate actual EEG from EOG artifact. While a number of EOG correction methods have been developed, these are primarily for vertical eye movements. Such procedures develop algorithms to determine the influence of eye movement at various electrode sites and may also take EOG and EEG frequency characteristics into consideration. Occular artifact in the present study came, however, from two dimensions, vertical and horizontal eye movement. While the use of eye movement correction procedures remains highly controversial when only one orientation (usually vertical) is involved, there has been little attempt to compute algorithms associated with both vertical and horizontal dimensions. On the other hand, it may be that the EOG electrodes were recording cerebral activity from the frontal electrode. Indeed, the EOG recordings of many subjects appeared to contain very peaked

waves, coinciding with those of the early waves of the event-related potential. Thus, the ocular activity may not be as pronounced as it appears.

P3 and Incidental Learning. The acquisition series of the incidental learning paradigm requires the subject to select the stimuli to be remembered from those to be ignored. Since the selection of a target might most expediently be based on the rather gross physical differences between pictures and words, the P3 associated with this decision was expected to occur relatively early, while finer discriminations might be associated with later positivities. A positive peak, P350, displayed the morphology and centro-parietal scalp distribution of the traditional "P3". Clear evidence of endogenous effects were observed for P350 in the picture waveforms. This wave was larger for the to-be-remembered pictures than the ignored pictures at acquisition. On the basis of the large literature linking P3 to task relevant decisions in target selection paradigms, a relatively early positive wave was expected to differentiate the to-be-remembered targets from the to-be-ignored "distractors". The P350 probably reflects an early decision-making process related to the task relevance of the stimulus.

P3 and prediction of memory performance. A positive, parietally maximum component at approximately 600 ms has been implicated in many ERP studies of the memory process, with larger amplitudes at acquisition associated with enhanced memory performance (Karis, Fabiani & Donchin, 1984; Sandquist, Rohrbaugh, Syndulko & Lindsley, 1980). This late positive wave is generally considered to be a P3 which has a late onset because of the complexity of the task. The relationship of P600 amplitude at acquisition with subsequent memory performance was examined in three ways. First, it was expected that the P600 wave would be larger for pictures since they are remembered better

than words. Second, intentionally learned stimuli were expected to elicit larger P600s since they are remembered better than incidentally learned stimuli. Third, a correlation between d' and P600 amplitude in averaged subject waveforms was expected to reveal a positive relationship.

As expected, the amplitude of the P600 wave was larger for pictures than words under all conditions. This result is consistent with reports that P3 is sensitive to differences in stimulus complexity (Johnson, 1986) and, by virtue of the superior recognition memory for pictures, implicates this wave in the encoding of items to memory.

In contrast to the limited number of memory studies finding that P3 amplitude at this latency predicts subsequent memory performance, P600 did not distinguish between incidentally learned and intentionally learned stimuli at acquisition. This effect is surprising since earlier waveforms had indicated that a decision regarding which stimuli to ignore had been made by 240 ms. Evidently, rehearsal or mnemonic strategy did not play a role in the development of this P600, unless one accepts the unlikely hypothesis that subjects rehearsed during both conditions. Despite the greater allocation of effort generally associated with learning a stimulus, compared to ignoring it, the effect on P600 appears to be equivalent.

There are two approaches that have been employed to investigate the effects of memorability of items on ERP waveforms. The first approach is a post-hoc procedure that returns to the acquisition series and averages the individual trial waveforms based on subsequent recall or recognition. The second approach is correlational, examining the covariation of the average ERP with overall memory performance. Both approaches have limitations. Sorting acquisition trials based on subsequent recall or recognition assumes that only

the processing of the stimulus at acquisition determines whether it will be remembered. Cognitive psychologists have provided considerable evidence to the contrary. The concepts of "encoding specificity" (Tulving & Thomson, 1971; Thomson, 1972, Eysenck, 1979; Jacoby & Craik, 1979) and "context-dependent learning" emphasize the effect of context on retrieval. In a recognition memory task, the context during retrieval involves discriminating the target stimuli from a set of distractors. The characteristics of the distractors also determine memory performance for any particular stimulus. A major model of these processes (Nelson, 1977) stresses the discriminability of the targets during the test phase as a key to successful retrieval. From this perspective, analysis of encoding operations on the basis of successful retrieval is problematic, especially in isolation. ERP activity during retrieval should also be recorded and analyzed independently. With a correlational approach, it is reasonable to expect that individuals who show strong memory performance will display enhanced ERP amplitudes if the latter reflects an important determinant of memory performance. This assumes a high degree of specificity in both the performance criteria and the ERP waveform, neither of which may be true. Thus, both post-hoc averaging of individual acquisition trials and the correlational method have limitations. In the present study, hardware limitations prevented the storage of single trials. For this reason, the correlational approach was adopted.

The correlational data observed for the two stimuli did not fall in the expected direction. Indeed they are very difficult to interpret. The P600 amplitude elicited at acquisition for the incidentally learned words group and the intentionally learned pictures group were negatively correlated with d' .

That is, larger amplitude P600s were associated with poorer subsequent recognition memory performance. There is, of course, the possibility that the negative association between P600 and better recognition memory performance was a spurious relationship, particularly because of the relatively small number of subjects ($n=10$ per group). On the other hand, several consistencies have been observed which render it an intriguing effect. The correlation was observed in two independent conditions at a statistically significant level, and was observed in the same direction for the two remaining conditions, although they did not reach significance. Furthermore, using verbal stimuli in a recognition memory paradigm, we have observed the same relationship in a population of children (Stelmack, Saxe, Noldy-Cullum, Campbell & Armitage, in press). Finally, the potential influence of an overlapping N400 at this latency remains undetermined. It is possible that the negative correlation of P600 with d' is a result of a direct relationship between d' and an overlapping negative wave.

P3 and decision making in the recognition memory task. For pictures, P350 was also larger for hits than either acquisition or CR waveforms. This result confirmed our expectation, since much previous literature has shown a relationship between P3 amplitude and performance in signal detection paradigms (Campbell et al., 1979; Hanson & Hillyard, 1984; Hillyard, K. Squires, Bauer & Lindsay, 1971; Kerkhof, 1982; Kerkhof & Uhlenbrock, 1981; Parasuraman & Beatty, 1980; Parasuraman et al., 1982; K. Squires et al., 1973a, 1975a,b; Sutton, Ruchkin, Munson, Keitzman & Hammer, 1982; Ruchkin, Sutton, Keitzman & Silver, 1980; Ruchkin, Sutton & Stega, 1980).

Multiple P3s in a recognition memory task. The observation that two "P3" components have been identified during this memory task is relatively unique.

Johnson and Donchin (1985) have recently presented evidence indicating that multiple P3s may appear in tasks which involve more than one decision. Since P3 latency is influenced by task difficulty, it is reasonable to assume that any task which is relatively complex might generate more than one P3 (Johnson & Donchin, 1985). This phenomenon has been most convincingly illustrated in paradigms which involve feedback. Such tasks require the subject not only to identify the stimulus, but also to continue processing the stimulus for further decision-making or discriminations. Stuss and Picton (1978) thus reported an early positivity (350 ms) and a later positivity (600 ms) during a feedback task. With pictorial stimuli, Johnson and his colleagues (Johnson et al., 1986) also report two positivities which they suggest reflect P3 activity. The morphology of their waveforms is very similar to those observed here. Their first P3 occurred at approximately 300 ms, and the second at 540 ms. Both components were sensitive to manipulations in the emotional value of the pictures.

N400 and contextual effects in the recognition memory task. The N500 component was of greater amplitude for words than pictures in both the intentional and incidental conditions for both acquisition and recognition phases of the task. One explanation for this finding is that the N500 reflects the physical mismatch between the picture and word stimuli. A frontally distributed negativity, the N200, which occurs earlier in less complex tasks, has been associated with physical mismatch (Naatanen & Gaillard, 1983; Naatanen, Sams & Alho, 1986; Naatanen, Simpson & Loveless, 1982). There is much debate regarding the equivalence of N200 and N400. The N500 observed here occurs at a latency which is sensitive not only to the picture/word differences, but also to other cognitive manipulations most

commonly associated with the N400 component.

A second interpretation of this component is that it reflects the processes of the N400 described by Kutas and Hillyard. In a recent review, Kutas and van Petten (in press) claim that with few exceptions, the N400 has only been obtained when the task is linguistic. There have, however, been few investigations of its effects using comparably meaningful nonverbal stimuli. At acquisition, the N500 in picture waveforms was not readily apparent in either the intentional or incidental condition, but seemed to be overridden by a parietally distributed positive waveform. The scalp topography defining the N400 has been a matter of some concern. Kutas and Hillyard (1980a,b) obtained N400s with a centro-parietal maximum at a latency of 300 to 600 ms poststimulus in response to unexpected endings of sentences. This component exhibited a left greater than right hemispheric asymmetry. When subjects were naming pictures, reading words and performing a mental rotation task, Stuss et al. (1986) observed frontally distributed "NP400" which was negative at the frontal lead but exhibited positive polarity at the occipital lead in the time range of 300 to 500 ms. This component was of greater amplitude over the right than left hemisphere. By contrast, Neville, Kutas and Schmidt (1982a) describe a frontally distributed negativity which was greater over the left than right hemisphere. These differences in scalp topography have led Kutas and van Petten to postulate the existence of two separate components, an N400 which has a posterior maximum, and responds to contextual semantic incongruity in linguistic contexts, and an N410 which is frontally maximum and elicited by isolated words presented for written identification (Neville, Kutas & Schmidt, 1982a, 1982b). The N410 described by Neville and her colleagues exhibits a left greater than right hemispheric asymmetry. Our N500 is more similar to

that described by Stuss et al. (1983,1986) in scalp topography. However, a great deal of overlap between the late positivities and negativities is often observed at this latency (Kutas & Hillyard, 1980c; Mulder, Brookhuis, Okita, Van Dellen, and Mulder, 1984; Stuss et al., 1986;). Differences in the scalp topography of these components would produce changes in the absolute amplitude of the waveform at this latency at each of the electrode sites. Moreover, insofar as the positive and negative components are affected differently by the requirements of the task, the relative involvement of the processes reflected by each of the components will alter the scalp topography from task to task. Thus it is difficult to identify the N400 process based solely on scalp topography.

Several investigators have noted the association between N400 amplitude and lack of priming (Kutas & Hillyard, 1984). For both stimuli, the amplitude of N500 was sensitive to the experimental manipulations which were expected to affect the extent of priming in memory. Priming effects are as yet not well understood. The concept of "priming" has been used in several different kinds of circumstances. "Priming" is currently used as a general concept which refers to the facilitation of performance on a task as a result of previously performing that task, or a similar task. It is also sometimes used to describe the process responsible for the effect of facilitation. Several explanations of the processes which lead to the phenomenon of priming have been offered. According to one body of theories (Atkinson and Juola, 1974; Morton, 1970; Collins and Loftus, 1975), when a word is presented for study the corresponding node in a lexical store is activated. Information about the recency of its presentation is represented by a reverberation of activity which dissipates over time, or a temporarily lowered excitability threshold.

This explanation is not easily reconciled with the persistence of priming effects which are evident over 24 hours (Jacoby & Dallas, 1981), 7 days (Tulving et al., 1982) or 12 months (Kolers, 1976). In an attempt to alleviate some of the difficulties with earlier priming models, Becker's verification model proposed that a series of tests is performed on the available sensory information. The order in which candidates are tested depends both on frequency of occurrence and context. The representations are always tested in descending order of frequency, but candidates suggested by the context have priority and are always tested first. Thus, in a recognition memory task, the presentation of items at acquisition may create an association between the larger experimental context and the targets. At the subsequent recognition test, the target words hold a position of priority and, based on incoming sensory information, are compared to the presented stimuli first. Using Becker's framework, N400 may reflect the process which is engaged when the stimuli which are weighted as the most likely candidates for presentation fail to match the current stimulus.

In these studies, the priming effect was expected to be manifested in three ways. First, the distractor stimuli in the recognition phase were expected to elicit larger N400s than the targets, since the distractors were novel stimuli, and had not been primed by the acquisition series. If there are differences in the storage of memory representations of pictures and words, as postulated by dual-coding theorists, then they should be reflected in the extent to which this relationship differed for pictures and words. In Experiment I, for both stimuli, N500 was larger during the recognition test than acquisition phase. In addition, in Experiment II, we observed that N500 was of larger amplitude for CR than hit responses. The presentation of the

target stimuli during the acquisition task activated or primed the representations of target stimuli. The CRs, on the other hand, are stimuli which have not been previously primed. For both pictures and words, the same wave, N500, reflected this difference between CRs and hits. Therefore, the process reflected by the N500 in this task is functionally similar for the two types of stimuli.

The second manifestation of the relationship between N500 and contextual effects was expected to be revealed by the intentional/incidental manipulation. At acquisition, the subject was asked to ignore the incidentally learned stimuli. During the recognition phase of the study, the performance measure, d' , indicated that these stimuli were more difficult to discriminate from distractors during the recognition task. It is probable that the subjects' investment of processing time and elaborative mnemonic strategies at encoding was greater for intentionally learned stimuli than incidentally learned stimuli. Thus, the degree of priming (or the priority in Becker's model) of the intentionally learned stimuli when presented during the recognition task was greater than that of the incidentally learned stimuli. Since N400 amplitude holds an inverse relationship with priming, the present N500 was expected to be augmented for incidentally learned stimuli compared to intentionally learned stimuli. Again, the extent to which this relationship held for both pictures and words was considered to be an index of the similarity of their retrieval systems. We had not predicted that the incidental/intentional differences would occur only for CR waveforms, and not for hits. However, it seems reasonable that stimuli which are recognized successfully, regardless of how they were learned, would have been associated with similar degrees of priming. For CRs the predicted

relationship between the manipulation of intent and N500 amplitude was observed for pictures. Incidentally learned pictures exhibited larger N500s than intentionally learned pictures. The limited extent of processing of the incidentally learned pictures compared to the intentionally learned pictures, may increase the difficulty of rejecting a possible match. Paradoxically, however, this effect was reversed for words. That is, for CRs, the N500s of intentionally learned words were larger than for incidentally learned words. While this effect is difficult to reconcile, it may be that recognizing the incidentally learned words was extremely difficult, and as a result, little effort was expended in memory search. The extremely low discriminability index (d') for this group seemed to have been characterized by a response bias favoring the "No" response, resulting in a disproportional number of miss and CR responses. The ERP waveforms for this group also indicated very little deviation from baseline at the latency of the N500 and subsequently. These data are consistent with the view that the incidental words condition was so difficult that little effort was expended on the task.

The third manifestation of the N400 as an index of the extent of priming or memory search, is found in a comparison of N400 for pictures and words. Both of the studies presented in this thesis are in support of the notion that N400 amplitude is associated with the extent of memory search in a recognition memory paradigm. Since the extent of memory search required is related to the ease of discriminability (d') of these items during a recognition test, we might also compare the N400 of pictures, which are better recognized, to the N400 of words, which are more poorly discriminated from distractors. Using N400 as an index of memory search, it might be concluded that verbal stimuli require a more extensive search than pictorial stimuli,

even at acquisition. The greater inherent physical distinctiveness of pictorial stimuli compared to words, aids both encoding and retrieval, and may serve to decrease the extent of the memory search required both during acquisition and the recognition memory task. Indeed, when the physical distinctiveness of pictorial stimuli is reduced, recognition memory accuracy is diminished (Nelson & Reed, 1976).

Slow wave and further processing. In both experiments, the slow wave (SW) exhibited a polarity reversal characterized by a frontal positivity which decreased in amplitude at Cz, and an occipital negativity, which decreased in amplitude at Pz. The SW was of greater amplitude for pictures than words for SW1 at Fz, Cz and the temporal sites, and for SW2 at Oz. The augmented activity at the occipital lead may indicate greater sensory specific involvement for pictures than words. In particular, the suggestion of an interaction between the frontal and the visual cortices is appealing in that it implicates the involvement of visual and spatial information as properties of strategic encoding. The salience of this type of information in remembering pictures compared to words may result in increased distinctiveness of the memory representation for pictures, and consequently, increased memory performance. In the first study, SW1 was larger for acquisition than recognition waveforms for both stimuli.

For pictures, SW2 was larger for acquisition and CR responses than for hits at all electrode locations except Oz. This effect may indicate that more effortful processing is demanded by the novelty of the stimuli. Items in the hit category had been presented previously in acquisition, while items presented as acquisition and CR stimuli were present only once. For words, this effect was in the same direction, however it was

only observed at the right temporal location.

For pictures only, SW3 was of greater amplitude for acquisition than hit or CR waveforms. It would appear that the processing of pictures during learning is maintained for a longer period than that of words. If this extended processing is involved in further elaborations of a representation in memory, then it may be associated with the superior ability to remember pictures. Complex novel stimuli such as unfamiliar shapes (Kok & deJong, 1980) have been shown to evoke late slow waves. Although the activity reflected by these slow waves is difficult to discern, they appear to manifest a continuation of refined stimulus analysis.

Implications for cognitive theory

It is significant that the recognition memory paradigm employed here provides a direct and independent analysis of acquisition and recognition memory phases since such a distinction cannot easily be made with psychophysical or neuropsychological approaches. As indicated in the analysis of recognition memory for pictures and words, there are several ERP components which differentiate pictures and words and that may serve the superior recognition memory for pictures. Further examination of these components would seem to hold a good deal of promise for advancing our understanding of this effect and of recognition memory in general.

The picture superiority effect must be a result of differences in the processing of pictorial and verbal information, and the associated memory representations. Functional differences in the processing of pictures and words have been examined here using event-related potentials of the brain. Changes in EEG activity which occur as a result of cognitive manipulations in a memory task give us some indication of the differences in functioning

associated with these two types of stimuli. The incidental learning paradigm was used in order to examine within-stimulus changes in memory accuracy, and associated changes in endogenous waves of the ERP. During acquisition, the processing differences associated with incidental versus intentional learning were expected to be reflected in the ERP waveform. Since intentionally learned stimuli were subsequently better recognized than incidentally learned stimuli, ERP differences between these conditions were assumed to be associated with differences in encoding, and these in turn, affect subsequent recognition. To the extent that these differences are observed in a similar manner for both pictures and words, the memory systems for pictures and words are considered similar in function. The within-stimulus comparisons of acquisition/recognition and hit/correct rejection waveforms also afford comparisons of the functional properties of the peaks for each stimulus. Differences and similarities of the picture and word waveforms with respect to these comparisons, as well as their implications for cognitive theories of picture and word processing, follow.

The ERP waveforms of pictures and word differed in several ways. Some very early processing differences were observed, which did not appear to be exogenous in nature. Pictures that were to-be-remembered were associated with greater positivity at 200 ms, 350 ms and 500 ms than those to-be-ignored. This effect of intention was not observed for words. Indeed, the P200 and P350 were not affected by any cognitive manipulation for words. Thus, picture and word processing appear to differ quite early during encoding. The early processing for pictures appears to be affected by intent (ie. is controlled), while similar processing for words is unaffected by intent (ie. is automatic). Saccadic eye movement

studies, picture/word interference tasks and priming studies indicate that much of the early phonological processing of words is automatic. The pattern of results obtained here is quite consistent with this view.

The picture acquisition waveforms were also observed to contain more positivity at latencies of 500 and 600 ms, and maintain augmented activity to the end of the sweep. Word waveforms, on the other hand, were more negative in polarity at 500 ms and 600 ms, and thereafter exhibited little deviation from baseline. These effects occurred regardless of intention for both stimuli. In some tasks, N400 and P600 have been observed to overlap in latency. However, the relative contribution of each is difficult to determine. It would appear that some interaction of increased negativity for words and augmented positivity for pictures has resulted in the observed amplitude differences. To the extent that this is the case, and that the N400 and P600 components are products of different generator networks, and have different functional properties, the processing of pictures and words at acquisition appears to differ. Overall, these acquisition data indicate that functional differences in the encoding of pictures and words are apparent in acquisition waveforms, and are present even at 250 ms. These findings at acquisition do little to differentiate a dual coding system from a unitary memory system. Both assume that prior to storage, pictorial and verbal information are processed differently, either in different systems (dual coding) or in the same system, with different order of access to phonological and semantic information.

Although the effects which were observed at acquisition served primarily to differentiate the processing of pictures and words, the recognition waveforms clearly revealed similarities. As outlined in the previous

section, the amplitude of N500 was quite consistently related to the extent of memory search (or lack of priming) associated with the task demands. These retrieval effects were very similar for pictures and words. For both stimuli, N500s for CRs were larger than for acquisition or hit waveforms. There is some consensus in the cognitive literature that when a stimulus is not immediately matched with a representation in memory (perhaps a primed representation), then an extensive search of memory ensues. Although it may be that processing differences which we were unable to measure differentiate picture and word processing, the properties of N500 do not seem to differ for pictures and words. Moreover, the N500 also distinguished between incidentally and intentionally learned stimuli for both pictures and words for correct rejection responses. For pictures, N500 was larger for incidentally learned than intentionally learned stimuli. The representations for incidentally learned pictures may have been more poorly established in memory. The overall diminished activity at acquisition for the ignored pictures attests to this. As a result, a more intensive search for matching stimuli was likely required for incidentally learned pictures in order to correctly reject the stimulus. On the other hand, for words, the correct rejection waveforms of intentionally learned words were of larger amplitude than incidentally learned words. Indeed, very little deviation from baseline is observed for the incidentally learned words. The very low d' , and high proportion of misses and correct rejections for this group suggest that the task of recognizing incidentally learned words might have been so difficult that little effort was expended, and memory search was considered unprofitable.

Dual coding theorists propose that verbal and perceptual knowledge are

"represented in different systems". That is, the system which deals with verbal information is functionally different from that which stores image information. If this were the case, it would seem reasonable to predict that the sources of activity in the brain associated with the retrieval of verbal and pictorial information would be very different. However, the measure of retrieval which we were able to obtain at the scalp for both stimuli was the N500 component. Although this effect was similar for both stimuli, we can not rule out the possibility that processing differences exist that we cannot measure at the scalp. However, no physiological evidence has been presented here to support the dual coding model. The cognitive manipulations employed in these studies affected the early portion of the acquisition waveforms differently for pictures and words, while the component most consistently associated with retrieval differences was sensitive to similar manipulations for both stimuli.

Where does this leave us with the young mnemonist studied so extensively by Luria (1968)? This young man never experienced the distortions of memory normally experienced in recall. All of the original information, and much more, was ultimately available for retrieval. Each word or object was intrinsically bound to a network of "extra" information. Sounds, images, scents, tastes and feelings formed synesthetic impressions of single letters and words or whole arrays of numbers. These impressions were so vividly associated with the stimulus that they sometimes interfered with its recall. A word might become lost in its own shadow, as described in the opening citation. The sensory information retained by the mnemonist seemed to aid a great deal in his ability to recall. Unlike the theorists who purport to a levels of processing approach, and for whom sensory information is seen

as shallow, and related to low success of recall, Nelson's sensory-semantic version of conceptual coding theory acknowledges the utility of sensory information in remembering. Indeed, to the extent that sensory encoding can render an input distinctive from other events, it is just as effective as semantic encoding. For Luria's mnemonist, this appears to be the case. Similarly, for the average university student the sensory information (the visual images of the letters and the phonology associated with them) derived from common words is overlearned, and does not readily distinguish one word from another. On the other hand, the pictures shown in a memory task are generally novel to the subject, and their physical form may more readily distinguish one picture from another. It is not surprising that our memory capacity, although perhaps not that of a mnemonist, is greater for pictures than words.

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