DEVELOPMENTAL ASPECTS OF THE SPACING EFFECT

by

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B.A., Simon Fraser University, 1979

M.A., Simon Fraser University, 1982

DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in the Department

of

Psychology

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SIMON FRASER UNIVERSITY

April, 1986

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ACKNOWLEDGMENTS

First, I would like to thank my Senior Supervisor, Dr. Vito Modigliani, for his invaluable help and advice with this project, as well as for his support and guidance during the course of my graduate studies. Second, I would like to thank the other members of my committee, Dr. Roger Blackman, Dr. Ray Koopman, and my External Examiner, Dr. G. Loftus, for his comments and interest in my research.

I am also indebted to Teresa MacInnes for her invaluable assistance in the preparation of audio tapes and data collection, and to Kitty Gustafson for extensive help in preparation of stimulus materials, manuscripts, etc. I would like to thank Wayne Tressel for technical assistance, Joan Foster for statistical and textform advice, and Val MacBean for editorial comments. And finally, thanks to friends and colleagues for support and understanding during my time in graduate school.

ABSTRACT

The spacing effect refers to the fact that repetitions which are spaced apart are remembered better then those which are adjacent or massed. Recently there has been a growing interest in this phenomenon in young children. The results of this small body of research, however, have been equivocal. For example, Cornell (1980) suggested that the spacing effect is the result of innate mechanisms, while Toppino and DiGeorge (1984) claimed that the spacing effect emerges with development. The present study was implemented in order to address issues raised by the above researchers and attempted to determine both the developmental course of the spacing effect, as well as some of the factors that may underly it.

Experiment 1 was a modified replication of Toppino and DiGeorge's study. Ninety-six children (24 each from 4 age groups; preschool, kindergarten, 1st and 3rd grade) served as subjects. Each child was presented with 4 lists (2 of words and 2 of pictures) and received a 2 minute free recall test at the end of each list. Mode of presentation was audio-visual. Items were presented either once (1P) or repeated twice at spacings (or lags) of 0, 1 or 3 intervening items. The results showed that the spacing effect was obtained for all age groups with both words and pictures, suggesting that the spacing effect does not emerge with development, but rather, may be the result of more fundamental mechanisms.

Experiment 2 focused on the role that very brief spacings, with no intervening items between repetitions, has on later retention. Ninety-six children served as subjects (24 each from preschool, kindergarten, 1st and 3rd grade). Each child was presented with 4 lists (2 of words and 2 of pictures) and received a 2 minute free recall at the end of each list. In addition to once presented items (1P) four different levels of spacing were included (0, 1.1, 2.5, and 5 secs.). The results of Experiment 2 demonstrated that the spacing effect was obtained using very brief <u>blank</u> intervals, for all age groups with both words and pictures.

The results of Experiments 1 and 2 are discussed in terms of the role of retrieval operations in producing the spacing effect. Further discussion focuses on implications of these findings for various theories of the spacing effect as well as directions for future research and possible practical applications.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

CHAPTER I

For over a hundred years it has been consistently demonstrated in numerous laboratory experiments that to-be-remembered items which are repeated have a higher probability of being recalled on a later test than those presented only once. More specifically, Ebbinghaus (1885/1964) noted that it took less time to learn a list of nonsense syllables if the repetitions were spaced over three days than if they were massed into one day. This is probably the first reported instance of the superiority of distributed practice over massed practice (i.e., the spacing effect). This finding aroused interest at the time and has been the subject of intensive laboratory investigations ever since (Cuddy & Jacoby, 1982; Glenberg, 1977, 1979; Hintzman,1974, 1976; Izawa, 1971; Melton, 1970; Underwood, 1961). McGeoch (1942) stated that the spacing effect "holds over so wide a range of conditions that it stands as one of our most general conclusions" (p. 119).

Stated more explicitly, the spacing effect refers to the general finding in most memory research paradigms, that when repetitions of to-be-remembered material are successive or massed, recall will be poorer than if they are distributed. Many theories have been postulated to account for this phenomenon and have received considerable empirical research. The strengths and weaknesses of these various theories will be discussed in the following section. Later, recent research which has adopted a developmental approach in investigating the spacing effect will be evaluated. The results of this literature review provide the rationale for the present study. Since the spacing effect is concerned with the effectiveness of rehearsal and repetition on memory it is necessary to begin with a discussion of the current empirical and theoretical status of these concepts.

Rehearsal, Repetition and Memory

"Practice makes perfect" is a familar adage and, as is the case with many such sayings, the statement has some truth to it. In relation to memory, the saying is often paraphrased as "rehearsal makes perfect". It has long been assumed that rehearsal is one of the best ways to increase retention of to-be-remembered material (Zechmeister & Nyberg, 1982). For example, drill and practice routines, such as those typically used in school situations with a variety of materials, are based on the notion that frequent and continuous repetitions improve memory. Repeating a telephone number or a name over and over is a common method used by people when faced with the task of trying to remember such items. Despite the popularity of rehearsal as a mnemonic strategy, the concept is not as straightforward as it would first appear and has been the object of much debate and research.

Research into the effects of rehearsal has spanned more than a century. For example, in one of his many studies, Ebbinghaus

(1885/1964) investigated the number of repetitions it took to master nonsense syllable lists of various lengths as well as the effect of overlearning on long term retention. Krueger (1929) elaborated further on this work and found that doubling the number of repetitions (200% overlearning) beyond mastery level had very little effect compared to 150% overlearning. However 150% overlearning gave a decided advantage over 100% overlearning.

Rehearsal has continued to be the object of empirical and theoretical investigations in research on memory up to the present time. While there is little doubt, in general, that rehearsal is an important strategy, exactly how rehearsal affects memory is much debated (e.g., Atkinson & Shiffrin, 1968; Craik & Lockhart, 1972). In fact the concept of rehearsal has changed substantially over the years as a result of the work of various researchers (Craik, 1979).

The most common assumption about rehearsal, and part of the usual definition, emphasizes the role of repetition (Johnson, 1980). Repetition and rehearsal, however, are not equivalent. For example, it is possible to rehearse an item by engaging in activities other than repetition, such as mental imagery, recoding, etc. Any definition which suggests that rehearsal and repetition are synonymous would be too narrow. Johnson (1980) pointed out that repetition is one form of rehearsal and that rehearsal involves a repetition that is internally generated by the learner rather than externally imposed. An externally initiated repetition, such as the re-presentation of an item, induces rehearsal only if the learner imposes some cognitive processing on the repeated information. Theoretically then, there is an equivalence between subject initiated rehearsal and repeated presentations which involve rehearsal. Likewise it would follow that successfully answered test questions following presentation of information would also be conceptually equivalent to rehearsal as defined by Johnson (1980). While the concept of rehearsal is theoretically straightforward, its operational definition and detection are much less so.

Some researchers assume that subjects rehearse whenever there is an opportunity (e.g., Shaffer & Shiffrin, 1972). Others have attempted to assess covert rehearsal through various means. Electromyograph potentials and lip reading have proven useful but limited, (e.g., Locke & Ginsberg, 1975). The use of pupillary size as an index of covert rehearsal is complicated because these responses are known to be influenced by other factors (Kahneman & Wright, 1971). The amount of time taken to study an item has also been used to assess rehearsal. When subjects are allowed to pace the presentation of material, the pauses can be taken as an indication that rehearsal is occurring (Belmont & Butterfield, 1971). A subject-paced study by Shaughnessy, Zimmerman and Underwood (1972) showed that better recall was related to time spent studying the material. Other studies, however, have found that duration of pauses were not closely related to accuracy of recall (e.g., Belmont &

Butterfield, 1971; Zimmerman, 1975).

In order to avoid the methodological problems of covert rehearsal a number of researchers have attempted to directly observe rehearsal by asking subjects to verbalize aloud (Izawa, 1976; Rundus, 1971; Whitten & Bjork, 1977). This technique does, however, raise the issue of whether overt and covert rehearsal can be equated. Johnson (1980) reviewed a number of studies which compared overt and covert rehearsal. Because of the complexity of the different conditions involved (e.g., type of rehearsal strategy, stimulus materials, etc.) the results of the review were equivocal. Johnson concluded that "it cannot be assumed that overt rehearsal is a mirror image of covert rehearsal" (p.263).

Not only are there difficulties in measuring rehearsal, but the converse experimental manipulation, that of preventing rehearsal, also presents methodological problems. The effectiveness of the various methods employed is difficult to assess. Some researchers have used rapid presentation rate in order to reduce rehearsal time (e.g., Waugh, 1970; Wenger, 1979). However, this method does not necessarily preclude the subject from rehearsing some part of the materials.

A more common strategy is to have subjects engage in some cognitive operation on an interpolated task. Petrusic and Jamieson (1978) found that most forgetting occurred as a result of shadowing as an interpolated task and that increasingly less forgetting occurred as a result of such tasks as listening to vocal music, listening to instrumental music, or leaving the interval blank. Thus, it would appear that in most situations the difficulty of the interpolated task is directly related to recall of previously presented material (see also Reitman, 1971, 1974). However, changes in the level of recall may not accurately reflect the occurrence of rehearsal. Poor recall does not necessarily mean a lack of rehearsal, and elevated levels of retention need not be assumed to be the result of more rehearsal (Dark & Loftus, 1976). A dimension other than difficulty may be involved. Ideally, interpolated tasks should be neutral with respect to the material to be remembered. Lack of neutrality may cause interference with memorization rather than merely preventing it (Reitman, 1974). Thus, it is not always clear whether it is the difficulty of the interpolated task or interference which causes changes in levels of retention.

Longer rehearsal periods usually result in higher levels of performance (e.g., Hockey, 1973; Penney, 1975; Rundus & Atkinson, 1970) although some instances have been reported where this is not the case (e.g., Glenberg, Smith & Green, 1977; Rundus, 1977). Increases in study time have been shown to affect immediate recall but not delayed recall (Modigliani & Seamon, 1974; Woodward, Bjork & Jongeward, 1973). Variables such as type of material and modality of presentation appear to play an important role. For example, in some studies longer rehearsal intervals enhanced recall for words but not for pictures

(Hintzman & Rogers, 1973; Ternes & Yuille, 1972). In contrast other researchers have found that increasing the time available for rehearsing led to an increase in memory for pictures (Graefe & Watkins, 1980; Tversky & Sherman, 1975; Weaver, 1974). There is also evidence that subject-generated images can be rehearsed (Peterson, Thomas & Johnson, 1977). The exact type of processing that is involved in rehearsal of pictures and images and how it relates to rehearsal of verbal material is difficult to ascertain.

Modality effects have also been investigated in relationship to rehearsal and memory. Auditory presentation compared to visual presentation was found to be consistently superior for short-term memory but only for recently presented items (Engle & Roberts, 1982; Penney, 1975). With long-term retention it has been shown that recall is greater for visual presentation than for auditory presentation (e.g., Melton, 1970). Listening comprehension has been shown to be substantially influenced by presentation variables. Wetstone & Friedlander (1974) found comprehension performance lowest for audio cassette and highest for videotape presentations.

It is apparent that the effectiveness of rehearsal varies as a function of many factors such as type of material, presentation modality, presentation rate, etc., and that its operational definition and detection pose methodological problems. Nevertheless, the concept of rehearsal has been crucial in most information-processing theories.

Most of the theoretical conceptualizations of memory, regardless of whether the focus is on structure (e.g., Atkinson & Shiffrin, 1968, 1971) or process (e.g., Craik & Lockhart, 1972), emphasize the role of rehearsal. For example, Atkinson & Shiffrin (1968) make it clear that without rehearsal, information in short-term memory (STM) will decay or be displaced by new information. In addition, rehearsal is also assumed to be an important mechanism for transferring information into the more permanent long-term memory. The explicit assumption in this model is that increased rehearsal is a basic factor in better long-term retention.

Other theorists (e.g., Craik & Lockhart, 1972) have argued that memory should not be conceptualized in this structural way, but, rather, that improved long-term retention is a function of the level-of-processing; the deeper the level the stronger the memory trace. Craik & Lockhart (1972), postulated the existence of two different types of rehearsal. Type I or maintenance rehearsal maintains to-be-remembered items at the same level of processing. That is, it involves the "repetition of analyses which have already been carried out" (p. 676). Thus, increased maintenance rehearsal does not improve recall. Type II or elaborative rehearsal involves the creation of more meaningful associations at a deeper level of analysis and consequently would benefit from longer rehearsal time (Craik & Watkins, 1973).

One problem with this model, however, is that it fails to provide a definition of depth that is independent of the nature of the tasks used to measure depth (Baddeley, 1978; Nelson, 1977). Baddeley (1982), however, supports the notion of levels as "domains" of processing. In addition, the levels-of-processing theory has been criticized for its claim that maintenance rehearsal would not lead to better long-term recall. There is much empirical evidence that same-level repetition can lead to better performance (e.g., Chabot, Miller & Juola, 1976; Dark & Loftus, 1976; Evans, 1977; Glenberg & Adams, 1978; Glenberg, Smith & Green, 1977). Thus, there is conflicting evidence regarding the role of the two types of rehearsal as postulated by levels-of-processing theorists.

Lack of empirical support for the existence of Type I rehearsal may be due to problems in definitions. Dark & Loftus (1976) made the important point that Type I rehearsal is not the same as rote repetition. The latter can produce either maintenance or elaborative rehearsal effects. Alternatively, the conflict may be resolved as outlined by Modigliani & Hedges (in preparation). These authors suggest that rehearsals are differentially effective as a function of spaced or massed practice. Rehearsals which are immediate and consecutive have minimal effects on retention, whereas distributed rehearsals have large effects. They suggest that those studies in which same-level rehearsal produced no effect, rehearsals were massed, whereas in studies where rehearsal was effective, subjects used distributed rehearsals. Modigliani and Hedges have provided some empirical evidence to support this notion and perhaps this analysis and further research can help resolve some of the conflicts regarding the effectiveness of same-level rehearsals.

We do not yet have a complete understanding of the effect of rehearsal on retention, but there is little doubt that most forms of rehearsal improve memory and that continued investigation of this process is warranted. It appears that the spacing between rehearsals or repetitions is a critical variable in determining optimal effectiveness in remembering. Many theories and empirical investigations have been directed toward understanding how and why spacing affects memory. I now turn to a consideration of the spacing effect which will be the major focus of the balance of this chapter.

The Spacing Effect

The spacing effect refers to the finding that items are better recalled if repetitions are spaced apart in time (distributed practice) rather than consecutive (massed practice) (Melton, 1970; Underwood, 1970). This phenomenon of memory has been demonstrated in a wide variety of laboratory memory tasks and conditions (Hintzman, 1974). The spacing effect has been found in paired-associate learning (e.g., Schwartz, 1975), free recall (e.g., Shaughnessy, 1977), and recognition memory (e.g., Hintzman & Block, 1970). Materials have included words (e.g., Whitten & Bjork, 1977), sentences (e.g., Underwood, 1970), pictures (e.g., Hintzman & Rogers, 1973), nonsense syllables (e.g., Kintsch, 1966), second language vocabulary (e.g., Bloom & Shuell, 1981), spelling lists (e.g., Reith, Axelrod, Anderson, Hathaway, Wood, & Fitzgerald, 1974) and telephone numbers (e.g., Landauer & Ross, 1977). Some of the dependent variables used have been frequency judgments (Proctor, 1980), probability of recall (Shaughnessy, 1977), verbal discrimination (Underwood, Kapelak, & Malmi, 1976), recognition and recognition latency (Johnson & Uhl, 1976). The effect has been found in auditory and visual modalities as well as mixed modalities in the same list (Hintzman, Block & Summers, 1973). The spacing effect is found over various presentation rates (Melton & Shulman, 1972; Whitten & Bjork, 1977) and occurs in within-list spacings (Maskarinec & Thompson, 1976) as well as between list spacings (Underwood, 1969). In addition to intentional learning experiments, the spacing effect has been found in incidental learning situations (e.g., Shaughnessy, 1976).

Although the spacing effect has been demonstrated with long intervals between repetitions and/or re-presentations (24 hours, Bloom & Shuell, 1981; one week, Glenberg & Lehmann, 1980) and with more than two presentations (Landauer & Bjork, 1978), most laboratory studies have employed a relatively restricted set of conditions. For instance, Hintzman (1974) excludes from his definition of the spacing effect intervals which exceed 15 seconds. The usual paradigm in laboratory experiments involves two presentations and a test (P1, P2, and T). Performance typically improves as the P1-P2 interval increases from zero to approximately fifteen seconds and then asymptotes. The length of the P2 to test (T) interval is usually held constant, and only the P1-P2 interval is varied (Hintzman, 1974).

The research interest in this phenomenon stems from the fact that it appears to be a theoretical anomaly. First, Underwood (1970) pointed out that the spacing effect violates the total time law. This law postulates that retention is a function of total study time and not how that time is distributed (Bugelski, 1962). Consequently it does not account for superior memory performance for distributed practice items, over massed practice items, where the amount of study time is the same regardless of spacing (Underwood, 1970).

Second, the law of recency would predict that the more recent items would be remembered better. In both massed practice and distributed practice the time interval between P2 and T is held constant. Consequently, P1 is more recent with respect to T in massed practice schedules, where it occurs next to P2, than it is in distributed practice schedules where it is separated by an interval. But, in contradiction to the law of recency, massed practice typically results in lower retention levels.

Third, if massed presentations of items occur infrequently in a list they should be distinctive and a von Restorff or isolation effect should occur (McLaughlin, 1965). Consequently, the retention of massed items should be raised. The typical results of most studies, however, show the opposite.

The spacing effect is therefore a theoretical puzzle. Yet, as Hintzman (1974) noted, it is a real and omnipresent phenomenon. Hintzman maintains that, in experiments where it is not demonstrated, the possibility of sampling error, ceiling effects, or some flaw in experimental design should be suspected.

There is much debate about why distributed practice facilitates memory and many theoretical interpretations have been formulated. Some of these theories postulate a single underlying process to account for the spacing effect while others have suggested multiple processes.

Single Process Accounts

The single process theories will be reviewed first and this review will follow an organizational scheme proposed by Hintzman (1976). He suggested that they can be classified under two general headings, encoding variability and deficient processing theories.

Encoding Variability Theories

Semantic Variability. This version of the encoding variability theory focuses on the fact that verbal items are to some extent ambiguous and can be interpreted in more than one way. Further, the more different meanings an encoded item has, the easier it is to retrieve. This hypothesis assumes that the semantic meaning given an item at P2 will be the same as that assigned at P1 if the repetitions are massed. When the interval is long, as in distributed practice, there is a greater likelihood that the P2 interpretation will change. Thus, distributed practice is assumed to produce greater retention than massed practice because there are more ways to retrieve items encoded in distributed practice (Melton, 1970).

For example, it is probable that the word IRON will be encoded differently when neighbouring list items are LEAD, COPPER, or ZINC, than when adjacent list items are SHIRT, WRINKLE, or STARCH (Crowder, 1976). While this is an extreme example it serves to make the point that words are semantically ambiguous and that the meaning assigned to them can vary with the contextual framework in which they are presented. It follows from the semantic encoding variability hypothesis that an item will be easier to recall if it has occurred in two contexts and therefore has two retrieval routes available to access the memory trace. Hintzman (1976) pointed out that there is very little empirical support for this hypothesis and a considerable body of evidence against it. Moreover, it has not been clearly demonstrated that long P1-P2 intervals do in fact produce two different semantic interpretations of an item and that short P1-P2 spacings produce only one (Hintzman, 1976).

Some researchers have suggested that if P1 and P2 encodings are different, then P2 should not be easily recognized as having been seen previously (e.g., Martin, 1972). The available evidence suggests that the opposite is true. Bellezza, Winkler and Andrasik (1975) reported that words recognized as "old" on P2 (and thus assumed to be encoded in the same way) led to better recall on the final test than those not recognized on P2, a direct contradiction of the hypothesis. Johnson and Uhl (1976) reported similar findings and suggested that recognition of an item as old at the occurrence of P2 may, in fact, be a necessary condition for the spacing effect.

A recent study (McFarland, Rhodes, & Frey, 1979) offered some support for a modification of the semantic variability hypothesis which stressed variations in features within a single semantic concept rather than independent semantic interpretations. Their results, however, were not conclusive enough to rule out other interpretations of the spacing effect, such as the attention hypothesis (see below).

Contextual Variability. A second version of the encoding variability hypothesis follows from Anderson and Bower's (1972) theory of retrieval. The contextual variability hypothesis proposes that encoding and storing items involves associations established between the meaning and attributes of to-be-remembered items and a conglomeration of contextual elements such as adjacent list words, the subjects' conscious thoughts, and environmental factors (Hintzman, 1976). The more contextual information that is available at retrieval, the more likely it is that an item that was presented previously will be recalled. Thus, the spacing effect is explained by the assumption that two presentations of an item that are spaced apart will involve a different set of contextual elements than if they are presented successively (Crowder, 1976).

The most convincing evidence for this hypothesis would be data showing that the spacing effect could be attenuated or eliminated by induced variation in context of P1 and P2 during massed practice. Experiments manipulating this variable have not supported the hypothesis (e.g., McFarland et al., 1979). For example, Wells and Kirsner (1974) found that switching the input modality between P1 and P2 does not reduce the effect.

According to the encoding variability hypothesis same or different orienting tasks accompanying both presentations of an item should have differential effects on the spacing effect by encouraging or discouraging different encodings. Specifically, when different orienting tasks are used for P1 and P2 in both massed and spaced conditions there should be no spacing effect. The results from various studies have shown that the spacing effect is just as great when the orienting task was different on

P1 and P2, as when it was the same (e.g., Bird, Nicholson & Ringer, 1978; Maskarinec & Thompson, 1976; Shaughnessy, 1976; Schwartz, 1975). These results were found in both free recall and incidental learning experiments, as well as cued recall studies. For example, Postman and Knecht (1983) found that encoding variability failed to increase either cued or free recall of target items and that increasing the number of retrieval routes was not a sufficient condition for improved recall. Moreover, Young and Bellezza (1982) demonstrated that encoding constancy resulted in better recall performance than encoding variability.

Taken as a whole, these studies pose serious problems for the encoding variability hypothesis as an adequate explanation for the spacing effect. A discussion of a modified and elaborated version of this hypothesis, the component levels theory (Glenberg, 1979) will follow later under the heading of multiple process accounts of the spacing effect. (p. 34).

Deficient Processing Theories

Under this general heading it is possible to categorize four different hypotheses: (1) consolidation (2) habituation (3) rehearsal, and (4) attention. Hintzman (1976) noted that the processes involved in rehearsal and attention can be assumed to be under voluntary control while habituation and consolidation are involuntary processes.

Consolidation. The essence of this hypothesis is that consolidation of memory traces takes place over time and uninterrupted consolidation will result in better recall than consolidation which is incomplete (Crowder, 1976). During massed practice, when P2 occurs immediately after P1, the consolidation processing of P1 is interrupted by P2. In distributed practice, on the other hand, the consolidation of P1 is assumed to be complete by the time P2 occurs. Thus, the superior recall associated with distributed practice is a result of more complete consolidation (Landauer, 1969, 1974). The usual assumption is that the short-term trace is the source of consolidation and that information is continually transferred from the short term state to the more permanent long-term state (Hintzman, 1974). It follows that if the same consolidation mechanism is involved in processing both occurrences of an item, then during massed practice there would be competition for its use and consequently a weaker long-term trace. Given this assumption, manipulations that interfere with the short-term retention of P1 should interrupt consolidation and create poorer long-term retention.

A study by Tzeng (1973) presented evidence which argued against the consolidation hypothesis. By varying the difficulty of the task that intervened between P1 and P2 but keeping the difficulty of the P2 - T task constant, Tzeng (1973) found that recall was directly related to task difficulty. In other words, recall was superior when the intervening task was difficult as opposed to when it was easy. These results add support to earlier and similar findings which provided evidence against consolidation as an adequate explanation of the spacing effect (e.g., Bjork & Allen, 1970).

It should be noted, however, that consolidation as a transfer process is not a necessary assumption. The concept of consolidation does not depend on the strength or even the existence of a short-term trace. For example, Wickelgren & Berian (1971) hypothesized that consolidation is the transformation of a potential memory trace into a retrievable trace and there is no need to invoke notions of short-term store or the transfer of information from short-term to long-term memory. In addition, evidence which demonstrates that the locus of the spacing effect is at P2 (e.g., Hintzman, Block & Summers, 1973) rather than at P1 as the consolidation hypothesis suggests, is not necessarily evidence against the hypothesis. Rather, as Hintzman (1976) has suggested, the hypothesis can be altered to its converse, that is, the continuing consolidation of P1 interferes with consolidation of P2.

A slightly altered version of the consolidation hypothesis proposes that differences in learning are due to two or more activity traces being consolidated into one single structural encoding during massed practice, whereas during spaced practice there are several separate structural encodings (Tarpy & Meyer, 1978). A serious problem for this theory is that the time taken for consolidation to occur has not been conclusively determined.

For example, electroconvulsive shock studies with animals, have suggested that the time may range from 15 seconds to more than an hour (Baddeley, 1976). However, learning studies have typically produced the spacing effect for periods of less than 15 seconds between P1 and P2.

It may be the case that consolidation is involved in the spacing effect but formulations and testings that attempted to delineate the underlyng process or processes have not been very productive. It would appear that it is lack of supportive, rather than the presence of contradictory evidence, that poses difficulties for the consolidation hypothesis (Hintzman, 1976). Another reason that this hypothesis has not been favoured by most researchers concerned with the spacing effect may be due to the lack of success in confirming the existence of a consolidation process in animal research (e.g., Miller & Springer, 1973).

Habituation. Like the consolidation hypothesis this is an involuntary processing model, with the locus of the spacing effect occurring during P2. The poor performance of massed practice compared to distributed practice is assumed to be a result of insufficient processing of the second occurrence of an item (Crowder, 1976). As long as the subject is devoting attention to P1, the process responsible for encoding continues to habituate or adapt. It only begins to recover when the stimulus (P1) is no longer present or when the subject stops attending to it. During distributed practice, recovery from habituation is complete by the time P2 occurs, whereas with massed practice, P2 occurs before recovery is complete, thus impairing retention (Hintzman, 1974). In order for P2 to be maximally effective it must occur outside the refractory period and so, from this perspective, the spacing curve is visualized as tracing out the time course of recovery from habituation.

In order to test this hypothesis, Hintzman, Summers and Block (1975), carried out an experiment in which degree of habituation was manipulated by varying the exposure time of P1 using durations of 2.2; 5.2 and 8.2 seconds. The results showed that spacing functions for all three durations were practically identical. If the habituation recovery hypothesis were correct then greater amounts of habituation due to longer exposure time should result in a slower recovery process and some predictable outcomes should be obtained. In addition, when items are presented several times in succession (experiment 2) the habituation hypothesis would also predict overhabituation and slower recovery. The results of Hintzman's et al. (1975) study did not support these predictions, and the general conclusion is that habituation would have to asymptote in less than 2.2 seconds for this hypothesis to be supported.

The habituation hypothesis also predicts that continued rehearsal of P1 should act to maintain habituation and inhibit full recovery. Thus, when P1 and P2 are spaced apart and subjects continue to rehearse P1 during the interval between P1 and P2 there should be no spacing effect. If a difficult task intervenes between P1 and P2 which prevents rehearsal then the habituation hypothesis would predict a spacing effect. Results from experiments by Bjork and Allen (1970) and Tzeng (1973) who varied the degree of difficulty of intervening tasks, support the habituation hypothesis. A more recent study by Proctor (1980), however, found that the spacing effect was eliminated when a difficult task intervened between P1 and P2. These conflicting results may be due to the different paradigms used (Pollatsek & Bettencourt, 1976).

Hintzman & Rogers (1973) attempted to manipulate rehearsal by using slides of complex visual scenes which it is assumed subjects are unable to rehearse (Shaffer & Shiffrin, 1972). In line with predictions from the habituation hypothesis the spacing effect was obtained. A problem with generalizing from this study is that the evidence regarding rehearsal of pictures is inconclusive (Graefe & Watkins, 1980). In general, however, it would appear that there is little conclusive empirical support for the habituation hypothesis.

<u>Attention</u>. This hypothesis proposes that subjects choose to pay less attention to P2 when it occurs adjacent to P1 than when they are spaced apart in time (Underwood, 1969, 1970). Thus, there is assumed to be less functional study time in massed practice than distributed practice and a resulting decrement in probability of recall. A number of assumptions underlie this

hypothesis. The first assumption is that there is a central limited capacity mechanism which is responsible for encoding, and that successive presentations must compete for its use. The second assumption is that the amount of processing given P2 is under voluntary control (Hintzman & Stern, 1977). A third assumption is that the total time law (i.e., that effective study time determines the amount learned) is correct. In other words, because distributed practice items are better recalled than massed practice items, even though they are equivalent in exposure time, it is assumed that study time is less effective under massed practice schedules. Furthermore, information is more redundant for massed practice items than for distributed practice items, because the information being presented is still available in memory.

Evidence in favour of this hypothesis accrues from studies where subjects are allowed control of the presentation of items (e.g., Zimmerman, 1975). When time spent studying each item was measured it was found that subjects spent less time on P2 when it followed P1 without a delay than when there was one. Similar findings have been reported in other studies using subject-paced procedures (e.g., Shaughnessy, Zimmerman & Underwood, 1972). A recent study by Wenger (1979) adds further support for the attention hypothesis and extends the generality of earlier findings by Waugh (1970). Using a paired-associate memory task and comparing two rates of presentation, fast (1.3 seconds) and slow (4 seconds), Wenger demonstrated that while there was a clear spacing effect at the slower rate, this effect was eliminated at the fast rate. The implication is that because subjects had difficulty encoding words sufficiently for recall at the fast rate, they were more likely to pay attention to both presentations in the massed practice condition. These data support the prediction of the attention hypothesis that when subjects were forced to pay attention to both occurrences of a massed repetition, there would be no attenuation of attention and consequently the spacing effect would be eliminated.

Studies which tested the idea that a limited-capacity central processing mechanism is involved in the spacing effect have produced results supporting this notion. Elmes, Greener and Wilkinson (1972) examined recall of the words which occurred immedately following P2. Those in the massed practice repetitions were recalled better than those in the distributed practice repetitions. This finding suggests that because less effort is expended in processing massed practice items there is more capacity available for the next item in the list and consequently better recall of those items. Similarly Johnston and Uhl (1976) reported that when auditory signals accompany P2 there is less likelihood that subjects will detect the signal as the P1 - P2 interval increase. The implication of this finding is that subjects have more capacity available during massed practice when less effort is being made to encode P2, than they do during encoding of P2 in distributed practice.

While the above findings favour an attenuation of attention explanation, results of other research pose some problems. First, Hintzman and Stern (1977) were unable to replicate the above mentioned study by Elmes, Greener, and Wilkinson, (1972). They suggested that the results obtained by Elmes et al. may have been an artifact of the procedures used. A number of methodological flaws in the study, such as the use of few primacy and recency buffers, confounding of spacing and serial position and/or items within the list, may have contributed to the results. In any case, the failure to replicate this study is a challenge to the attention hypothesis. Second, proponents of the attention hypothesis argue that the mechanism responsible for the spacing effect is not an automatic process but is consciously controlled by the subject. Therefore, a critical test for the hypothesis would have to demonstrate the existence of voluntary processes underlying the spacing effect. Evidence against this notion comes from a number of studies.

For example, Hintzman, Summers, Eki and Moore (1975), attempted to manipulate the degree of voluntary attention that subjects paid presentations, but were unsuccessful in eliminating the spacing effect. Their conclusion was that the underlying mechanism is not under voluntary control. Likewise, Elmes, Sanders and Dovel (1973), in a free recall experiment, tried to allocate subjects' attention to the second occurrence of items regardless of spacing, through use of the isolation or von Restorff effect. The critically selected items were in either a highly distinctive voice (auditory list) or distinctive typeface (visual list). Elmes et al. (1972) showed a facilitative effect of isolation on the recall of spaced items compared to massed items. This clearly demonstrated that the spacing effect was not diminished by isolation, a contradiction to the hypothesis that voluntary processes underlie the spacing effect.

A similar finding was reported by Hintzman (1976) where monetary incentives were used in order to manipulate subjects' attention. Again the spacing effect was not attenuated. While these studies are not conclusive, they fail to confirm specific predictions of the attention hypothesis.

Other studies have presented additional problems for the attention hypothesis (e.g., D'Agostino & DeRemer, 1973; Maskarinec & Thompson, 1976). For example, Underwood, Kapelak, and Malmi (1976) attempted, in a number of experiments, to discover situations in which the size of the spacing effect varied as a function of other factors. Four different situations were examined: (1) recognition of letters, (2) verbal discrimination, (3) short free recall lists, and (4) recall of twice presented massed practice items with intervening items inserted to promote forgetting. The spacing effect was demonstrated in all studies and Underwood et al., (1976) pointed out that their data cannot be accounted for by any of the current massed practice-distributed practice theories. In particular, their Experiment IV poses serious problems for the attenuation of the attention hypothesis. Attenuation results when the material being presented becomes redundant if it is still available in memory. Underwood et al., (1976) attempted to produce an equivalent recall level for both distributed practice and massed practice items by inducing forgetting for P1 under both schedules. Their results showed that this manipulation did not influence the spacing effect as the attention hypothesis would predict.

There may be a number of conceptual problems related to the inconclusive and conflicting results obtained in studies testing the attention hypothesis. First, the term attention often lacks a precise operational definition. Exactly what is meant by attention is not clearly specified in the literature concerned with investigating the spacing effect. If voluntary mechanisms are involved, then attention may be conceptualized as a precursor or necessary precondition for cognitive processing such as encoding, associating, rehearsing, etc., to take place. In this sense attention is a corollary to perceiving. However, some researchers (e.g., Hintzman, Summers, Eki & Moore, 1975; Shaughnessy, Zimmerman & Underwood, 1974; Zimmerman, 1975) use the term attention interchangeably with cognitive processing activities such as encoding, elaborating, or associating. In other words, they do not operationally define attention as a separate mechanism from activities such as rehearsal.

A second conceptual problem with the attention hypothesis relates to the distinction between voluntary and involuntary processes. It is logical to assume that when subjects engage in cognitive activities such as rehearsal (e.g., as measured overtly) they are paying attention to the material to be memorized. However, the converse is not necessarily true. When subjects do not actively rehearse or engage in active cognitive processes of some kind, they may still pay attention to the stimulus being presented. In this view attention is conceptualized as a passive process which does not involve voluntary cognitive activity, but may involve automatic perceptual mechanisms. Following this line of reasoning to its logical conclusion, the distinction between voluntary and involuntary attention becomes blurred.

If attention is conceptualized strictly as a voluntary process, the main question of interest is why do subjects tend to devote less attention to massed practice items compared to distributed practice items? One answer is that subjects assume they know the massed practice item, and if they are confident of being able to remember the item, they will not give further attention to its second presentation. Zeichmeister and Shaughnessy (1980) showed that when subjects are asked to rate, at the time of study, the likelihood of recalling individual items, massed practice items were rated higher, but remembered less well than distributed practice items. If subjects believe they have remembered an item, then very little further processing is given to that item. Obviously, there is an interaction of voluntary attention and rehearsal or other encoding processes and this poses problems for the attention hypothesis. It would appear that attention (however defined) may be necessary but not sufficient to account for the spacing effect. When subjects do attend to the items being presented, the questions of interest are, what kind of processing activity do they engage in, and what are the variables of importance that determine later recall? The rehearsal hypothesis addresses these questions.

Rehearsal. The rehearsal hypothesis is based on the notion that subjects rehearse P1 information. When the P1-P2 interval is long there is a greater probability that P1 information will get some rehearsal compared to when the P1-P2 interval is short (Atkinson & Shiffrin, 1968). This hypothesis follows the same logic as the consolidation hypothesis in that the locus of the spacing effect is assumed to be a function of P1 rather than P2, and the emphasis is on the relationship between total processing time and long-term storage strength (Crowder, 1976). Unlike the consolidation hypothesis, however, the rehearsal hypothesis assumes that the critical processing is under the subject's conscious, voluntary control. An experiment by Rundus (1971), which investigated overt rehearsal patterns, tended to support this hypothesis. He found that when the spacing between presentations was short there was less total rehearsal time given to the critical items than when the spacing was long.

Modigliani & Hedges (in preparation) noted that subjects learning lists of words in an overt rehearsal situation tended to give distributed rehearsals to some words, and immediate, consecutive rehearsals to others. An analysis of the data demonstrated that words receiving distributed rehearsal were much more likely to be recalled than words which were rehearsed in a massed manner. Thus, it would appear that rehearsal effectiveness is not simply a function of total rehearsal time (i.e., Rundus, 1971) but, rather, is a result of a distributed rehearsal strategy. In other words, as the P1-P2 interval increases, subjects are more likely to give some distributed rehearsals to P1 information before the occurrence of P2. When the P1-P2 interval is short, subjects are more likely to give massed practice to P1 information and the probability of a distributed rehearsal is reduced.

Evidence against the rehearsal hypothesis comes from a number of studies (e.g., Bjork & Allen, 1970; Tzeng, 1973). Bjork and Allen (1970) using a modified Brown-Peterson distractor task (Peterson & Peterson, 1959) found that recall was greater when a more difficult task intervened between repeated presentations than when an easier one did. These results were confirmed and extended by Tzeng (1973) using a similar modified Brown-Peterson paradigm. It would appear that the rehearsal hypothesis is challenged to the extent that a distractor task interferes with short-term retention in proportion to its difficulty.

The results of a later study by Pollatsek and Bettencourt (1976), however, suggest that the findings of both Bjork & Allen (1970) and Tzeng (1973) have little applicability to the spacing effect obtained with tasks other than the Brown-Peterson paradigm. They demonstrated that the spacing effect in the Brown-Peterson task is a function of reduction in proactive interference from previous trials, and that when the amount of proactive interference was controlled there was no spacing effect. Thus, the better retention that results when a difficult rather than an easy task intervenes between repetitions is the result of a greater decrease in proactive interference from previous trials. Pollatsek & Bettencourt (1976) suggested that the findings of Bjork & Allen (1970), and Tzeng (1973) cannot be generalized beyond the distractor task.

Other arguments against the rehearsal hypothesis focus on the manipulation of the to-be-remembered material. Some researchers have claimed that subjects do not rehearse complex visual scenes (e.g., Shaffer & Shiffrin, 1972). It would follow that if rehearsal is the cause of the spacing effect, then use of material which subjects do not rehearse (i.e., pictures) should eliminate the spacing effect. Hintzman & Rogers (1973) using colour vacation slides as stimulus material obtained the spacing effect. Likewise, Hintzman, Summers & Block (1975) found a spacing effect using similar material. Hintzman et al. (1975) base their argument against the rehearsal hypothesis on the notion that subjects do not rehearse pictures. As previously noted, there is sufficient evidence to suggest that this is not the case and that subjects do rehearse pictures (Graefe & Watkins, 1980; Tversky & Sherman, 1975; Weaver, 1974; Peterson et al., 1977). Consequently, Hintzman's et al. (1973, 1975) conclusions have to be viewed with caution.

A more serious problem for the rehearsal hypothesis however comes from studies which use an incidental learning paradigm (e.g., Jensen & Freund, 1981; Rowe & Rose, 1974; Shaughnessy, 1976). In these studies subjects ostensibly have no reason to rehearse critical items and consequently the spacing effect should be eliminated. Contrary to this prediction Shaughnessy (1976), Jensen & Freund (1981), and others have reported the persistence of the spacing effect in incidental learning situations.

There are, however, inconsistencies associated with incidental learning tasks. For example, it has been demonstrated that incidental learning tasks such as judgments of the pleasantness of words, are consistently followed by higher recall, than tasks which involve judgments of frequency (Postman & Kruesi, 1977). Indeed, incidental learners who are required to make pleasantness ratings usually recall more than intentional learners who are unencumbered by an orienting task (Hyde & Jenkins, 1973; Walsh & Jenkins, 1973). Furthermore, Postman (1964) suggested that there is little or no reason to maintain a conceptual distinction between intentional and incidental learning. In other words, while the data from various experiments have shown quantitative differences between instructions-to-learn groups and incidental learning groups, all that can be concluded is that learning is more difficult under the former conditions than the latter (McLaughlin, 1965). The mechanism underlying learning in both cases can be assumed to be the same.

In addition, the incidental procedure does not necessarily preclude the possibility of rehearsal of target items, it merely presents more obstacles to learning in those situations. In imposing an incidental learning task, the experimenter does not, as is often implied, gain full control over the subject's encoding activities. More important to the present discussion, Postman and Kreusi (1977), have shown that performance on incidental or orienting tasks does not necessarily depend on the semantic or nonsemantic nature of the task. Rather, it seems that the critical factor is the extent to which these tasks elicit displaced rehearsals. In order to accurately rate an item in an incidental task, the subject must retrieve and compare previous list items. Shaughnessy (1976) has pointed out that such comparisions entail displaced rehearsals and that these comparisions also help in establishing a network of inter-item associations. Moreover, Postman & Kruesi (1977), have provided evidence that displaced rehearsals tend to decrease as the nature of the incidental task changes from subjective ratings of attributes to objective ratings. All of the above mentioned problems may be confounding factors in studies which use incidental tasks as a test of the rehearsal hypothesis. In other words, the results of these studies may simply reflect variations in the amount of displaced rehearsals which are an artifact of different aspects of the rating task.

The above discussion makes it clear that, in general, single process accounts of the spacing effect have not fared well. Next I will evaluate another class of theories which attempt to explain the spacing effect by postulating multiple processes. The first of these, and perhaps the most prominent theory of the spacing effect, is derived from the encoding variability hypothesis. This is the component-levels theory (Glenberg, 1979). The second class of theory is derived from the levels-of-processing model of memory (Craik & Lockhart, 1972) and has been variously referred to as the reconstruction theory or the effort theory.

Multiple Process Accounts

Component Levels Theory

Glenberg (1979) has formulated the component levels theory to account for the spacing effect. This theory is an expansion of the encoding variability hypothesis discussed earlier. Its first basic principle is that a repetition is potentially effective for retention to the degree that the second presentation allows for the storage of information distinct from that stored at the first presentation. Moreover, it is assumed that a memory trace is a store of information in the form of attributes or components. Glenberg delineated three types of components: contextual, structural, and descriptive.

Contextual components include such information as the physical environment in which an event occurs, the learner's affective and cognitive states as well as temporal aspects of the situation. Structural components involve the structure the subject imposes on the events happening within the learning situtation. For example, subjects may associate items, categorize the material or attempt to chunk items together. Descriptive components constitute the properties of an individual event. They include information as to the orthography, articulation and meaning of a to-be-remembered item and reflect the semantic memory representations of the stimulus in its current context. For example, requiring subjects to process the pronunciation and sound of a set of rhyming stimuli would create similar descriptive components in all the traces.

Glenberg's (1979) theory accounts for the typical spacing effect by assuming that the traces of an item repeated at long spacings or lags have more variability than the traces of an item repeated during massed trials or short spacings or lags. In other words, according to the component-levels theory, increasing the spacing between repetitions results in an increasing amount of contextual information stored with the second presentation of the repeated item. Recall (in a free recall test) is assumed to be a positive function of the match between this stored contextual information and the contextual information available at the test.

One prediction from Glenberg's (1979) theory is that the free recall of words that are repeated in a list improves monotonically with increases in the number of other list items separating the repetitions. According to Glenberg, subjects organize a list during its presentation into overlapping groups of interassociated words. The second presentation of a repeated item can be grouped with either the same items as at the first presentation or with different items. The theory assumes that as the lag or spacing between repeated items increases, the probability that a repeated item is grouped with different items also increases. In other words, as the lag increases the groups of words associated with the first and second presentation tend to overlap less and less. Since an item repeated after a long lag is associated with more different groups than an item repeated after a short lag, a monotonically increasing lag effect is predicted.

Different predictions, however, are made with cued recall. In cued recall, Glenberg reasoned that, unlike the free recall situation where all groups of interassociated words formed during list presentation would have an equal probability of being accessed, cues in the cued recall condition would make some word groups more accessible than others. In the shorter lags a cue would provide access to groups of words associated with both presentations of a repeated item. For example, if cued recall is compared at lags 2, 5, and 17, recall should improve from lag 2 to lag 5, because lag 5 items would be associated with more different groups of words. On the other hand recall would be expected to decline at lag 17 because each presentation constitutes two separate non-overlapping sets and the cue would be associated only with one set. During cued recall access would be only to that subset of word groups that had been associated with that specific presentation and would result in poorer performance than at the shorter lags. Glenberg's (1977) results supported his theory. In the cued recall condition performance improved from lag 2 to lag 5 and then declined at lag 17. In the free recall condition performance improved steadily with increasing lag.

This experiment, as well as other research by Glenberg and his associates (Glenberg, 1974, 1977, 1979; Glenberg & Lehman, 1980; Glenberg & Smith, 1981) has provided support for the component-levels theory. The theory is, however, somewhat less than parsimonious in accounting for many of the results of other researchers (e.g., Johnson & Uhl, 1976; Madigan, 1969; Ross & Landauer, 1978). Glenberg (1979) has admitted that the explanatory power of the component levels theory may "have been purchased,... at the expense of simplicity" (p.109). The important question is whether this more cumbersome theoretical account of the spacing effect provides any explanatory advances over simpler accounts. Several findings by other researchers cast doubts on the validity of Glenberg's theory.

For example, the component-levels theory makes the point that the spacing effect results from the fact that each repetition of a to-be-remembered item is represented in memory by functionally separate traces. Therefore, a recognition measure at the second presentation of an item can be assumed to be an indication of the amount of activation of encodings involved at both presentations. That is, if the subject does not recognize the second presentation of an item as such, this can be interpreted as an indication of a large difference in the encodings in the first and second presentations. Those items not recognized at the second presentation should be variably encoded and, according to component-levels theory, be better recalled. On the other hand, items that are recognized at the second presentation as having been seen previously, would indicate that similar encodings were active at both presentations and poorer recall would be predicted.

Results of a study by Johnston & Uhl (1976) found the exact opposite. Using the recognition paradigm just described it was shown that items not recongnized at the second presentation were recalled poorly. Only items recognized as "old" on their second presentation contributed to the spacing effect. Madigan (1969) reported similar results in a free recall experiment. Likewise, Bellezza, Winkler & Andrasik (1975) reported that words recognized on the second presentation led to better recall on the final test than those not so recognized. This is a direct contradiction of the hypothesis.

An argument in favour of the component-levels theory would point to the fact that if encoding variability is conceptualized as the addition of new information to the same representation, it need not be assumed that functionally separate traces have to be created to achieve the spacing effect (Glenberg, 1979). However, the component-levels theory does not provide an explanation of how the trace of the first representation is located in order for new information to be added at the second presentation.

A similar problem for the component-levels theory was raised by Ross and Landauer (1978). Simply put, they reasoned that increasing the spacing between the two presentations of a repeated word increases the total number of contextual components stored in that word's representation in memory and this produces the spacing effect. It would logically follow that increasing the spacing between pairs of once presented words should likewise increase the total number of contextual components stored in their two separate representations. Thus, Ross and Landauer propose a correspondence between a single word presented twice and two words each presented once.

According to the component-levels theory the conditions of study and the conditions of testing interact to determine the spacing effect. The free recall spacing effect is the result of context matching at the time of testing. Both the repeated word and the once presented words are equivalent in the degree to which the context at the test matches contextual elements in one or the other of the once presented words. Any prediction that is made regarding the spacing effect of repeated items would also apply to the two once-presented items. In other words, if the free recall spacing effect is due to context matching, recall of at least one (one or the other or both) of the two once-presented words should also produce a spacing effect.

Ross and Landauer (1978) failed to obtain a spacing effect for two items each presented once for either recognition or free recall, but in every case there were spacing effects for twice presented items. Likewise, Glenberg and Smith (1981) using an approach similar to that of Ross and Landauer, failed to obtain the predicted spacing effect for two once-presented words. Glenberg and Lehman (1980) did, however, find a spacing effect but only when once-presented words were paired with once presented words in a second list. It may be that context matching is an adequate explanation of between-lists spacing but not of within list spacing.

Other studies have also provided evidence that pose problems for Glenberg's theory. As noted, Glenberg predicts a nonmonotonic effect only for <u>cued</u> recall and a monotonic effect for <u>free</u> recall. Foos and Smith (1974), however, reported a nonmonotonic lag effect in free recall. In addition, Toppino and Gracen (1985) failed, in nine separate experiments, to replicate Glenberg's (1977) earlier results. It is difficult to point to any specific aspect of Toppino and Gracen's procedures which might account for this replication failure.

It seems clear that Glenberg's component levels theory has not received conclusive empirical support and indeed, there would appear to be much evidence against this account of the spacing effect.

Levels-of-Processing Theories

An alternative to the component-levels theory as an explanation of the spacing effect derives from the levels-of-processing point of view (Craik & Lockhart, 1972). Various formulations which have this theme in common have been proposed (e.g., Jacoby 1978; Lockhart, Craik & Jacoby 1976; Rose, 1980; Rose & Rowe 1976). In essence, the explanation is based on the notion that when an item is repeated in a list or sequence, the subject attempts to contact the memory trace of the first presentation. When items are massed or repeated closely together, the subject need not process the second presentation to the same extent as the first because contact is made relatively easily by scanning recent episodic memory. The subject, in this case, can recall the end product of the processing of the first presentation and consequently makes relatively less processing effort at the second presentation. As the spacings between repetitions increase, more effort than mere scanning must be engaged in, and the subject must approximate the encoding effort of the first presentation.

According to Jacoby (1978) the subject must reconstruct or repeat the processes used for the initial presentation. A basic assumption of this theory is that the reconstruction process involves a deeper level of processing than the scanning process and this leads to better long-term retention. Thus, it is implicit in this view that a necessary condition for improved retention is not variable encoding but encoding at a deeper level. According to the component-levels theory, as the spacing between repetitions increases the traces of the repetitions contain much variability among their components, including cognitive encodings of the repetitions. The levels-of-processing view, on the other hand, suggests the opposite. As the spacing between repetitions increases the encoding of these repetitions becomes more and not less similar; the second one being, in essence, a replica of the first.

The previous discussion of Glenberg's (1979) component-levels theory suggests that enforcing <u>similar</u> encodings of repeated items would eliminate the spacing effect and produce a relatively low level of recall whereas enforcing <u>differential</u> encodings of all repetitions would lead to relatively higher levels of recall, again with no spacing effect. The levels-of-processing hypothesis, on the other hand, suggests that the same manipulation would produce the spacing effect for enforced similar encodings but not for enforced differential encoding. A study by Rose (1980) testing this hypothesis found support for the levels-of- processing view but not for the component-levels approach.

In a variant of the levels-of-processing theory, Jacoby (1978), developed the interesting notion that a reconstruction process has a critical influence on the spacing effect. The basic assumption in this approach is that the task of memorizing a list of words, for most subjects, is comparable to the task of solving a series of problems. When a problem to be solved is presented twice and at the second presentation the solution from the first presentation is remembered, long-term retention will suffer compared to a situation where reconstruction of the solution is required at the second presentation. Jacoby's (1978) data provided support for the basic notion that as spacings increase the probability of the reconstruction of P1 increases and it is this factor which accounts for the beneficial effects of repetitions at long spacings relative to short spacings.

Cuddy and Jacoby (1982) developed the levels-of-processing view further. They suggested that remembering a prior presentation of an item when that item is repeated reduces the amount of processing of the repetition, but that with increased spacing the subject is less likely to recognize an item as being a repetition, and reconstruction of the processing of the repeated item will be more likely to take place. Thus, the probability of reconstruction of the processing of the repeated item increases as the memory of the initial presentation becomes partially forgotten or inaccessible. Paradoxically this view suggests that forgetting helps memory.

One problem with the above formulation is the need for some measure of forgetting or partial forgetting between repetitions that is independent of the phenomenon which it attempts to explain (i.e., subsequent retention performance). Rose (1984) examined processing time for a repetition compared to processing time for the initial presentation in an attempt to solve this problem. In his experiments he used the differences in response time to the first and second presentation as a measure of forgetting of the initial presentation of the item. Rose reasoned that as spacing increased, the time required to process the repetition due to some degree of forgetting will also increase. In other words, the amount of reconstructive processing of the repetition will increase with the amount of forgetting and there should be a positive correlation between processing time of a repetition and later retention performance. Thus, memory performance is related to savings in the time required to process repetitions.

In two experiments Rose (1984) used several levels of spacing and used frequency judgment as the main measure of memory performance. In addition, memory was also measured in terms of the probability of a correct recognition, and in the second experiment, performance on a recall task which preceded the frequency judgments was also measured. The subjects in the experiments were asked a simple question of a semantic nature which required a response of yes or no. For some subjects the words in the list were repeated with the same question and for others with a different question on each repetition. The reaction time on this task was used as an estimate of the time required to process each presentation. According to the reconstruction hypothesis, spacing should have similar effects on both reaction time for repetitions, and memory performance for repeated items. When the same question accompanied each presentation of a repeated word both reaction time and performance increased over spacing. The effects of spacing on reaction time and memory performance (judged frequency) in the different-question condition were similar in that both attenuated and no spacing effect was obtained.

Rose (1984) pointed out that his results were generally in agreement with the reconstruction hypothesis and presented some problems for Glenberg's (1979) component-levels theory. For example, the component-levels theory cannot account for the higher mean judgments of frequency with repeated encodings (i.e., same question) rather than with variable encodings (different questions) found in Rose's (1984) experiment and in previous studies (e.g., Hintzman & Stern, 1977; Rose, 1980). There is an obvious need for a reconciliation of the degree of encoding variability with the degree of encoding similarity necessary for spacing to have an effect.

Other support for the validity of the reconstruction theory comes from studies that used an independent measure of the amount of processing effort required in both massed and spaced repetitions (Magliero, 1983; Silverstein, 1978). A common theme of the theories of Jacoby (1978; Cuddy & Jacoby 1982) and Rose (1984; Rose & Rowe 1976) is that both emphasize the importance of operations performed on to-be-remembered words, and the consequences of bypassing these operations. They explain the spacing effect by assuming that massed repetitions receive less processing than spaced repetitions. One problem in providing support for these ideas has been the difficulty of measuring the amount of processing allocated to items. Probe reaction time tasks (Posner & Boies, 1971) have been used in some studies (e.g., Johnston & Uhl, 1976) but a problem with this methodology is that the requirement to perform dual tasks may have an unpredictable effect on the memory task itself.

One possibility of measuring the amount of processing unobtrusively is to use psychophysiological measures. For example, Kahneman (1973) and Kahneman and Beatty (1966) have measured the relationship between processing effort and pupil dilation. They found that increasing the amount of memory processing increases pupil diameter. A literature search revealed only two studies which investigated the spacing effect using psychophysiological measuring. Silverstein (1978) used heart rate and skin conductance measures (GSR) to examine the effects of massed versus distributed repetitions of verbal material. Physiological responses to repeated items were smaller when they were massed than when they were spaced. The usual spacing effect was found in the recall data.

Magliero (1983) used a measure of pupil dilation in experiments investigating the spacing effect with pairs of identical words (Exp. I) and pairs of related words (Exp. II). The spacing effect was found with pairs of identical words using lags of 0, 1, 4, and 8 intervening items, but not for pairs of related words. In both conditions however, it was found that small dilations were observed at short spacings and relatively large dilations at longer spacings.

The theories of Jacoby (1978) and Rose (1984) provide explanations of why there would be less processing for massed presentations compared to spaced presentations of identical and related words. Both these positions emphasized the importance of elaborations following an item presentation. If the product of earlier elaborations is easily retrieved then little encoding effort is required by a repetition. For spaced repetitions earlier operations cannot be easily retrieved and reconstructions must be performed. Thus, the resulting increase in pupil dilation across various lags.

With related words, Magliero (1983) suggested that subjects used an organizational strategy which allowed interitem associations to be formed for massed presentations and that these associations were formed with little effort. Evidence for this proposition comes from a number of studies.

First, Ambler & Maples (1977) provided evidence to support the notion that semantic organization can be performed by an automatic system that requires relatively little conscious cognitive processing. Thus, organizational strategies are facilitated by massed presentations but interfered with by spaced presentations. Consequently, the level of retention decreased for related words, but the amount of effort as measured by pupil dilation, increased for various spacing lengths.

Second, studies have shown that when related words occur in close proximity in a list they are remembered better than when they are spaced further apart (e.g., Glanzer, 1969, free recall; Hintzman, Summers & Block, 1975, recognition memory; Jacoby & Hendriks, 1973). Thus, encoding of related words frequently produces a flat or even reverse spacing function compared to encodings for identical words (Hintzman, 1976).

Third, evidence that processing of some kind goes on with the presentation of related words, even though it results in a lower level of recall compared to spacing of identical words, comes from a number of studies. For example, Rundus (1971) found that the presentation of a word during the study phase of an experiment reminded subjects of an associate that occurred earlier in the list. Subjects instructed to rehearse aloud during the study of free recall lists tended to rehearse related words together. Words that had been dropped from the rehearsal set were included again after the presentation of a related word. Gruneberg (1972), also found that subjects were able to detect associative relationships between words that were spaced widely apart in a list. It would appear that study phase retrieval involving cognitive processes occurs with repetitions of associatively related items just as it does with repetitions of the same item. The results of these studies lend support to Magliero's interpretation of the pupillary data found with related words (Experiment II).

The theories of Jacoby (1978) and Rose (1984) are supported by the data from these psychophysiological studies. It is clear that less processing (as measured by psychophysiological entities) is allocated to massed repetitions than to spaced repetitions.

However, what is not so clear is exactly what kind of cognitive processes are being performed by the subjects under various conditions. The fact that, in Magliero's (1983) study, the pupillary data were very similar for Exp. 1 (identical words) and Exp. 2 (related words) even though the spacing effect was not obtained in the latter, illustrates the problem of attempting to map psychological processes onto physiological data, or of determining the exact correspondence between the two.

Another problem with the use of psychophysiological measures is that GSR and pupillary responses can be influenced by factors other than the one under investigation (Kahneman & Wright, 1971). In addition, psychophysiological measures may be limited in their use to situations which involve slow presentation rates. For example, problems would arise if one were attempting to measure, via psychophysiological means, the different amount of cognitive processing as a function of factors such as slow (4 seconds) and fast (1 second) presentation rates. Magliero (1983), found that a 6 second interstimulus interval (ISI) was optimal to allow recovery from pupil dilation. Consequently, it would be difficult to investigate the effects of various presentation rates given that pupil dilations take at a minimum 4 seconds to recover between items (Kahneman & Peavler, 1969).

Similarly, use of heart rate and skin conductance responses pose problems in that both reduce in magnitude at a fairly rapid rate (Davis, 1970; Gatchel & Gass, 1976). That is, with short ISI's, habituation tends to occur faster than with longer ISI's. Thus, when identical items are massed, the lower magnitude of response compared to that at longer spacings may be a function of an habituation process that may have little to do with cognitve processing.

Although the reconstruction (Jacoby, 1978) and levels-of-processing theories (Rose, 1980) provide a satisfactory account of the spacing effect they may be limited in their generality. Experiments which show that increasing the lengths of spacing beyond a few minutes, and which still obtain the spacing effect, (e.g., Glenberg & Lehman, 1980) suggest that mechanisms other than cognitive effort may be responsible for the spacing effect over longer intervals. For instance, Magliero (1983) noted that pupil dilation reached asymptote at a spacing of 4 intervening items. To the extent that magnitude of pupil dilation reflects mental effort the above proposition that other mechanisms are involved, seems to be supported.

Conclusion

It seems clear that the spacing effect is a phenomenon that can be reliably obtained using various paradigms (e.g., continuous paired-associate, free recall, frequency judgments, etc.) and with a wide variety of materials such as word lists, pictures, nonsense syllables, sentences, etc. (Crowder, 1976; Hintzman, 1976). The question of major theoretical interest, however, has remained unanswered. Exactly why spaced repetitions of to-be-remembered items engender better memory than massed repetitions is still not clear. The above discussion of the literature on this topic has shown that many theories have been postulated and submitted to extensive empirical investigation. While conclusive support for any single theory has not yet emerged, the available evidence suggests a number of potentially productive approaches. One possible line of research involves a variation of the reconstruction hypothesis which focuses on retrieval operations. A second potentially valuable approach involves investigating the cause of the spacing effect from a developmental perspective. These ideas will be elaborated upon in the next chapter.

CHAPTER II

Although the spacing effect is an unusually robust phenomenon, it nevertheless remains a theoretical puzzle. To date no single theoretical account of the spacing effect has proven completely satisfactory. Many theories have been proposed, (e.g., consolidation, encoding variability, component-levels, etc.) but have been shown to have little or no empirical support. Other theories, while not unequivocally disconfirmed, have not been conclusively supported. A number of these are worth further consideration. For example the attention, reconstruction, and rehearsal hypotheses may at least supply partial answers to this theoretical anomaly.

The present study focused on a particular variation of the reconstruction/rehearsal ideas, namely the retrieval operations hypothesis. Briefly, this position suggests that a retrieval event associated with the second presentation of an item is important for the spacing effect to be demonstrated. In addition a developmental perspective was adopted in the present investigation in an attempt to delineate the mechanisms underlying the spacing effect through use of a younger population.

The next section will elaborate on the retrieval operations hypothesis and discuss the advantages of taking a developmental approach in studying the spacing effect. This will be followed by an explanation of the rationale for the experiments to be reported later.

The Retrieval Operations Hypothesis

First, consider the rehearsal hypothesis. This position attributes the spacing effect to the fact that the critical processing occurs between P1 and P2 (Hintzman, 1976). From this perspective subjects are believed to rehearse the target items during the P1 - P2 interval when items are spaced, but this extra rehearsal is not possible during massed presentations when P1 and P2 are contiguous (Rundus, 1971). The hypothesis proposed in this study incorporates this assumption, but suggests that this explanation by itself is inadequate. Rather, the focal point of the retrieval operations hypothesis is that the key mechanism involved in the spacing effect is the occurrence of a *retrieval event*.

Related to this notion is Jacoby's (1978) reconstruction hypothesis. This position suggests that when subjects are given the task of learning a list of words, this is essentially equivalent to the task of solving problems. Jacoby accounts for the beneficial effects of spacing by suggesting that when the solution to the problem is still present at the time of the second presentation (P2), then mere scanning of recent episodic memory is all that is necessary in terms of processing at P2. However, if P2 is spaced apart from P1, then some reconstruction of the original solution will be necessary and it is this reconstruction process that is assumed to underlie the stronger memory performance of distributed items. Thus, Jacoby's position suggests that a retrieval operation in the form of reconstruction is a crucial variable in the spacing effect. What is being suggested here is that this may be only one form of retrieval operation and perhaps not the only one. For example, the retrieval event may be triggered internally by the subject, or externally by environmental stimuli such as test questions, re-presentations or cues provided by the experimenter, and may involve automatic processes in addition to conscious attempts to remember. When retrieval attempts are successful the probability of the item being recalled on a later test is very high compared to items not retrieved (Modigliani, 1976). Successful recall of items has been shown to have a potentiating or strengthening effect on those items (Izawa, 1971). When items are repeated in succession such as in massed practice or lag 0, where P1 and P2 occur contiguously, P2 is not likely to be a retrieval of P1 (Zimmerman, 1975). As the spacing between P1 and P2 increases the probability of a retrieval event occurring at P2 also increases.

Evidence in support of this proposition comes from an incidental finding in a study by Hintzman, Summers, & Block (1975). Using slides of scenes, various exposure times and the recognition memory paradigm these researchers showed that even a brief spacing of .8 seconds improved retention compared to zero spacing. When memory for twice presented items at a 2.2 second duration with a .8 second blackout in between, was compared to memory for a single presentation with duration of 5.2 seconds, the small spacing of .8 seconds produced better recall. Likewise when items presented three times (2.2 second duration each, with two .8 second spacings between presentations), were compared to an item continuously presented for 8.2 seconds the effect of these very short spacings produced significant improvements in memory. This improvement occurred despite the fact that the total study time for the interrupted stimulus was less, compared to the uninterrupted stimulus.

These results can be interpreted as evidence for the occurrence of a retrieval operation at P2 in the interrupted stimulus case, and that better recall was not simply a matter of additional rehearsal time. The difference in recall between the once presented item and the interrupted stimulus presentation was very small and only statistically significant in the case of the thrice presented item. This suggests that the probability of a retrieval event occurring at such a short spacing was quite low but occurred some of the time at least. As the P1 to P2 interval increases, the probability of a retrieval event taking place also increases and the differences in recall between massed and spaced items likewise increases. Furthermore, the retrieval operation hypothesis also suggests that it is only those items which involve a retrieval event that actually contribute to the spacing effect and not merely spacing _per se_. In other words, retrieval events can occur during both massed practice (where there is usually a brief interstimulus interval) and distributed practice but the probability is increased in the latter case.

For example, Rea and Modigliani (1985) used an expanded series of tests and re-presentations which resulted in very high and equivalent levels of recall for both massed and distributed conditions during the study phase of the experiment. However, on a delayed test given one minute after the study phase, the distributed practice group recalled almost twice as much as the massed practice group - a dramatic difference. These results can be interpreted in light of the retrieval operations hypothesis. Even though recall on test questions was equivalent in both conditions during the study phase, the probability of a retrieval event using massed practice was minimal, whereas with an expanded test series, the probability of a retrieval event was high. Evidence from other studies which found the same pattern (e.g., Bloom & Shuell, 1981), lends support to this proposition.

Thus, the key mechanism that is assumed to underlie the spacing effect is a retrieval operation (i.e., retrieval of P1 at P2 or during the P1 to P2 interval). Most studies attempting to find support for, or argue against various theories of the spacing effect (e.g., rehearsal, attention) have not paid attention to this particular factor. For example, introducing distraction activities during the P1 to P2 interval in order to preclude rehearsal, does not prevent the occurrence of the retrieval of P1 at P2 but may merely reduce the probability somewhat (e.g., Bjork & Allen, 1970; Tzeng, 1973).

It may be that processes other than retrieval operations are involved in the spacing effect, but delineation of these processes pose problems. For example, it is difficult to separate out such factors as attentional mechanisms from retrieval operations when attention is probably necessary for the occurrence of the spacing effect. Manipulation of variables which contribute to retrieval events may also involve increasing the probability of preliminary attentional mechanisms. Although a retrieval operation is probably a fundamental mechanism necessary for the spacing effect, other processes may also contribute depending on the particular paradigm used, the population being tested, etc. A problem with testing the retrieval operations hypothesis using adults as subjects is that these subjects typically engage in a variety of control processes besides those of interest to the experimenter. Thus, it would be difficult to disentangle the effects of retrieval events from those of other processes with this subject population. An alternative approach is to use less sophisticated subjects, i.e., young children, in research investigating the spacing effect.

Developmental Approaches to the Spacing Effect

As the previous review showed, over the last two decades there have been many experiments investigating the spacing effect in adults. Most of these studies demonstrated the spacing effect in a wide variety of circumstances but, in general, failed to provide an unequivocal theoretical account. There is another orientation that may help illuminate the mechanisms underlying the spacing effect. This is the developmental approach.

A review of the literature has revealed very few studies which have taken this approach in investigating the spacing effect (i.e., Cornell, 1980; Toppino & DeMesquita, 1984; Toppino & DiGeorge, 1984; Wilson, 1976).

Wilson tested a modified encoding variability hypothesis using 4th graders, 8th graders, and adults and found that the spacing function varied with age. For the younger group (4th graders) recall increased significantly with a spacing (or lag) of 2 intervening items compared to lag 0, but there was no increase beyond lag 2. That is, items spaced with 8 intervening items between presentations did not enhance recall. For the older groups (8th graders and adults) recall did not increase significantly between lag 0 and lag 2 but did increase between 2 and 8 intervening items. Although Wilson attempted to account for his data with a number of hypothesized mechanisms derived from his modified encoding variability hypothesis, there were many theoretical and empirical flaws in his analysis (e.g., inaccurate assumptions regarding children's and adult's STM capacity; children's use of metamemorial strategies, etc.; see Chi, 1976). More importantly, the finding in Wilson's study that 8th graders and adults did not demonstrate a difference in recall between spacings of 0 to 2, is contrary to most studies investigating the spacing effect (e.g., Glenberg, 1979; Rose, 1980). The reasons for the absence of a spacing effect in this population are not clear but some methodological flaws may have contributed to the results.

Although Wilson's study was far from conclusive and his hypothesized mechanisms were inadequate for explaining the spacing effect in either adults or children, it was the first study to explore the spacing effect from a developmental perspective. As such, it constituted an important empirical innovation. Wilson's (1976) developmental study was followed by Toppino and DeMesquita (1984) who assessed free recall performance as a function of spacings or lags of 0, 3, and 6, in three elementary schools grades (1, 3 and 6).

In their first experiment, they found that there was significant improvement for all children from lag 0 to lag 3 but no significant improvements from lag 3 to lag 6. In addition, overall performance increased with age; the older children remembered more that the younger ones. The pattern of results obtained by Toppino and DeMesquita (1984) suggests that the spacing effect is obtained only at short lags in elementary school children and that this effect undergoes relatively little change during elementary school years. In addition, these results are consistent with Wilson's conclusion that the lag effect is different for children than for adults. In their first experiment, Toppino & DeMesquita (1984) did not directly address the question of <u>why</u> spaced-repetition effects are different for children than for adults.

In a second experiment Toppino & DeMesquita (1984) tested the encoding variability hypothesis using grade 3 and grade 6 students as subjects. They attempted to control directly the encoding process by using a same-different orienting task that required children to make judgments about each word as it was presented. When a different orienting task is used on each presentation of an item, encoding variability theory would predict that no spacing effect should be obtained because all repetitions would be encoded differently regardless of lag. On the other hand, Toppino and DeMesquita argued that when the same orienting task is used on each presentation there should be "some increase in performance as a function of lag because increased spacing would produce differential encoding regardless of the orienting task" (p.40). It should be noted at this point that this latter prediction is in contradiction to most encoding variability theories (see Glenberg, 1974,1977,1979; also Rose, 1980; Magliero, 1983; Shaughnessy, 1976).

Interestingly enough, Toppino & DeMesquita found that when the encoding task induced children to encode repetitions differently there was no lag effect. However, when the same-orienting task was used for each repetition, performance improved significantly from lag 0 to lag 3 but not from lag 3 to lag 6. In addition they found that enforced differential encoding was superior to the same encoding condition but only at lag 0 and not at lag 3 or lag 6. This pattern of results was the same for both 3rd and 6th graders.

These results lend support to theories that predict no lag effect for enforced differential encoding of repetitions (e.g., Glenberg, 1979; Jacoby, 1978) but, to some extent, argue against theories that predict a lag effect for enforced similar encodings. Thus, encoding variability theories such as Glenberg (1979) which predict the former but not the latter are only partially supported by these findings. Theories based on levels-of-processing (i.e., Jacoby, 1978) fare somewhat better in that the results found here are generally in line with theoretical predictions. However, the levels-of-processing approach does not provide an explanation for the lack of improvement from lag 3 to lag 6 in the same-orienting task condition. Exactly why performance for both grade 3 and grade 6 students increased from lag 0 to lag 3, but did not from lag 3 to lag 6 is unexplained by either the levels-of-processing or the encoding variability theories.

A study by Cornell (1980), has provided some support for the notion that the spacing effect reflects a fundamental and automatic process of memory. Working with pre-verbal infants (5-6 months) he found that when tested for recognition of briefly presented photographs of faces they exhibited the typical spacing effect. It has been shown that young infants tend to look at a novel picture more than at a previously exposed one (e.g., Fagan, 1975). Cornell exposed babies to pictures of human faces for 20 seconds each. Repetitions were spaced at either 3 seconds (massed condition) or 1 minute apart (distributed condition). After a retention interval (either 5 seconds, 1 minute, 5 minutes, or 1 hour) a recognition test was administered in which the infants were exposed to two pictures side by side, one of which was new and one of which was a previously presented picture. Preference for viewing the new face was interpreted as evidence for recognition of the old face.

The results of the study indicated that infants showed a preference for the new face following massed repetitions but not following spaced repetitions on the recognition test following retention intervals of 1 minute, 5 minutes and 1 hour. Interestingly enough, there was no difference between the massed and distributed conditions during the four study periods and on the immediate (5 seconds) recognition test. The distributed pattern of exposures facilitated memory of the pictures compared to close successive presentations, even up to 1 hour later.

These results suggest that the spacing effect may involve a fundamental, spontaneous and automatic process of memory.

It should be noted, however, that the existence of a primitive encoding mechanism in infant's recognition memory does not preclude the contributions of other mechanisms such as strategic control processes in older children and adults. In addition, Cornell's (1980) infant recognition procedures and materials are quite different from the procedures used to study the spacing effect in many other memory experiments (e.g., verbal material and free recall). Moreover, Cornell's retention data do not offer conclusive support for any particular theory of the spacing effect and can be interpreted in terms of a number of theories (e.g., encoding variability theory, attention theory etc.). His learning-phase data, however, argue against habituation as an explanation of the spaced repetition effect. According to the habituation hypothesis the infants should show decreasing interest in items that are massed compared to distributed in the study phase. The results were contrary to this expectation. Infants exhibited the same visual behaviours and attention patterns in both the massed and distributed conditions throughout the learning phase of the study.

In an attempt to shed further light on the relative role of automatic processes and other cognitive strategies on the spacing effect, Toppino & DiGeorge (1984) conducted a free recall study involving preschoolers (mean age 4.33 years), and first graders (mean age 6.66 years). The materials used were pictures of unrelated common objects which the children were required to label as each was presented. Their results indicated that the younger children did not benefit from distributed repetitions; they recalled massed and spaced repetitions equally well. In contrast, the first graders recalled spaced items better than massed items. Both groups, however, benefited from repetitions: repeated items were recalled better than once-presented items.

These findings, if reliable, would place constraints on the notion that there is an automatic mechanism underlying the spacing effect in free recall. Rather, as Toppino & DiGeorge (1984) suggest, the spacing effect in free recall appears to depend on the development of other mechanisms. Any basic or primitive mechanism that contributes to the distributed-repetition effect may be restricted to recognition memory as demonstrated by Cornell (1980). Thus, explanations that rely solely on automatic encoding processes would appear to be inadequate accounts of the spacing effect. If Toppino & DiGeorge are correct, the incorporation of cognitive processes that emerge with development such as attentional or rehearsal strategies, would seem to be necessary for any adequate theory.

The class of theory that seems most compatible with Toppino & DiGeorge's results is a deficient-processing theory which proposes that subjects adopt a voluntary strategy in which they do not attend to and fully process the second presentation of a massed item. Subjects tend to devote more attention to the second presentation of an item as spacing increases. It is possible that this attentional strategy is a developmental trend and is acquired between the ages of 4 and 6 years. Research investigating developmental trends in selective attention, concept formation, etc., would tend to support this account of the data (e.g., Hagan & Stanovich, 1977; Toppino, Lee, Johnson, & Shishko, 1979). However, with the paucity of published research on the developmental aspects of the spacing effect it is difficult to draw any firm conclusions regarding specific theoretical formulations.

Toppino & DiGeorge's statement that young children (4 years old) do not benefit from spaced practice with pictures is based on a small sample in one study. There is an obvious need for further research to test specific theories and attempt to discover what developmental factors lead to the emergence of the spacing effect in children. Research in this area would help delineate the mechanisms or processes underlying the spacing effect in general.

Rationale for the Present Study

As noted, only four published studies to date have adopted a developmental orientation (Cornell, 1980; Toppino & DiGeorge, 1984; Toppino & DeMesquita, 1984; Wilson, 1976). The results of these studies and their theoretical orientations are summarized in Table 1.

TABLE 1

DEVELOPMENTAL STUDIES OF SPACING EFFECT

Researcher	Population	Sample Size	Method	Theory Tested	Outcome
Wilson (1976)	4th graders 8th graders College Students	24 24 24	Visual presentation (5 sec., rate): 38 word list; lags 0, 2, 8 and 1P; 3 minute written free recal test.	encoding variability (spacing or lag effect)	Lag function varied with age. Grade 4: lag effect 0 to 2 but not 2 to 8. Grade 8 and college students: lag effect 2 to 8 but not 0 to 2.
Cornell (1980)	Infants (5 to 6 months)	115	Habituation paradigm; visual performance apparatus; B/W picture of faces. Massed practice (4 study trials, 3 seconds apart) vs Distributed practice (4 study trials, 60 seconds apart). Recognition memory test.	automatic process (spacing effect)	Obtained spacing effect. Basic process of recognition memory are automatic and do not change with development.
Toppino & DeMesquita (1984) 1st. Exp.	1st grade 3rd Grade 6th grade	18 18 18	Visual presentation (5 sec., rate); 21 word list; lags 0, 3 and 6. (words were also spoken for 1st grade). 3 minute oral free recall test.	no specific theory but mechanism thought to be organizational strategies	Lag effect obtained from 0 to 3 but not from 3 to 6 for all subjects

Table 1 (con't)

Researcher	Population	Sample Size	Method	Theory Tested	Outcome
2nd Exp.	3rd grade 6th grade	24 24	Audio presentation (4 sec., rate); 33 word list; same/different orienting tasks; lags 0, 3 and 6. 3 minute oral free recall.	encoding variability (spacing or lag effect)	no support for Wilson's encoding hypothesis. Lag effect from 0 - 3 (same condition). lag effect from 0 - 3, not from 3 to 6 (different condition).
Toppino & DiGeorge (1984) 1st Exp.	Preschoolers	20	Visual presentation (5 sec., rate); 16 pictures of common objects; lags 0, 3, and 1P. Children had to label pictures. 3 minute oral free recall	automatic process (spacing effect)	no spacing effect (evidence against Cornell's (1980) automatic process)
2nd Exp.	Preschoolers 1st graders	18 18	Visual presentation (5 sec., rate); 16 pictures of common objects; lags 0, 3, and 1P. Children had to label pictures. 3 minute oral free recall.	deficient processing supported (i.e., voluntary attention)	no spacing effect found for preschoolers. Spacing effect found with 1st graders.

From Table 1 it can be seen that the spacing effect has been demonstrated with 5 - 6 month old infants (Cornell, 1980) and with 1st, 3rd and 6th graders (Toppino & DiGeorge, 1984; Toppino & DeMesquita, 1984). The effect was obtained from lag 0 to lag 3 but not for lag 6. Consistent with the above results, Wilson (1976) found a spacing effect with 4th graders from lag 0 to lag 2 but not for lag 8. The spacing effect, however, was not obtained with preschoolers (Toppino & DiGeorge, 1984). Thus, overall, the developmental data present an unclear picture.

There are a number of problems associated with these studies which limit their generality. First, an analysis of Wilson's (1976) study indicated a number of methodological and theoretical problems. Second, Cornell's (1980) study is also limited. The materials and procedures used by Cornell (i.e., the habituation paradigm and facial recognition) are quite different from those normally used in studies investigating the spacing effect. The results of a later study by Toppino & DiGeorge using preschoolers (average age 4.3 years) and pictures of objects, failed to obtain the spacing effect. These authors suggested that if there is a basic or fundamental process involved in the spacing effect it may be limited to facial recognition in preverbal infants.

The evidence that the spacing effect emerges with development rests, at the moment, on a single study by Toppino & DiGeorge (1984) who found no spacing effect for preschoolers. It is important to examine this study carefully.

First, they reported that they used manual presentation of pictures at a 5 second rate. This procedure has little to recommend it. Timing accuracy is a crucial variable in the presentation of visual stimuli and any variation can have a dramatic effect on subsequent performance. Loftus and Kallmam (1979) reported that very brief variations in exposure time can have substantial effects on recognition memory. Furthermore, Loftus (1982) pointed out that not only is precise control over exposure time critical, but that "hand presentation should be used only as a last resort" (p 265). In relation to this, another variable of importance, which Toppino and DiGeorge (1984) did not report, was the length of the interval between the presentation of pictures. As mentioned previously, blank time between presentations of as little as .8 seconds can have an effect on later recall. In addition, Modigliani's (1976) results suggest that delaying the second presentation of an item for only a very brief period (less than two seconds) can have a major effect on the probability of a later recall. Consequently, precise control over the interstimulus interval for repeated items is of critical importance in experiments investigating the spacing effect. Furthermore, Toppino & DiGeorge did not report the size of the pictures used in their experiment and size has been shown to be a critical variable influencing later performance (Loftus, 1982).

Additional problems may have arisen from the use of pictures. Toppino & DiGeorge used a free recall test to measure memory of pictures. A requirement of verbal recall of pictures is that it involves transforming visual information about the pictures into verbal codes and storing these in memory. Thus, the oral recall test not only measures retrieval ability per se (i.e., retrieval of pictorial information), but also the amount of stored verbal information. While the evidence regarding developmental differences in the free recall of pictures is not conclusive (Pressley, 1977), the differences observed by Toppino and DiGeorge between the two groups (preschoolers & 1st graders) may have reflected differential verbal processing of pictorial information. In other words, the older children may be more capable of utilizing verbal encoding processes. Thus, better recall in this group compared to the younger group, may be a function of the degree to which the spacing of repetitions facilitates this process. For the younger children there may have been no such facilitative effect and consequently no spacing effect. While the above proposition is speculative, a conclusive test of this issue would be to include a condition which used word lists in addition to pictures with these populations.

Another point of interest in Toppino and DiGeorge's data is the very high levels of recall for both preschoolers and first graders. Preschoolers recalled 34.7% of the massed items and 32% of the spaced items, whereas the 1st graders recalled 37.5% and 54.2%, respectively. Of special note was that preschooler's recall of the massed items was almost equivalent to that of 1st graders. This is an unusual finding in light of the results of other developmental research which has consistently found increases in recall across various age groups (e.g, Flavell, Friedrichs, & Hoyt, 1970; Perlmutter & Myers, 1979). A reasonable expectation based on this developmental research would be a much lower level of recall for preschoolers compared to 1st graders. Although Toppino and DiGeorge did not address this issue, I believe it to be of importance in the interpretation of their data.

Toppino and DiGeorge conclude that 1st graders benefited from spaced practice compared to massed practice and that preschoolers did not. However, the equivalence in recall between preschoolers and 1st graders noted above raises an alternative possibility. That is, for whatever reasons, it may be that massed practice items were functionally equivalent to distributed practice items for the preschoolers. If this were the case, then the conclusion that the spacing effect emerges with development is questionable.

Further evidence for this line of reasoning comes from an examination of Toppino and DiGeorge's data for once presented items (1P). Preschoolers recalled substantially less of the 1P items (13.8%) compared to the 1st graders (20.8%). This is congruent with the above mentioned developmental research findings. Given this difference in recall for 1P items, one would predict some intermediate level of recall of massed items for preschoolers compared to 1st graders. Yet they both increased their level of recall to approximately the same level for massed items. For the preschoolers this increase represented a difference of 20.8% and for the 1st graders a difference of 16.7%. Thus, massed practice benefited preschoolers as much, if not more, than 1st graders. If, as suggested, massed items were for some reason, functionally more similar to distributed practice for preschoolers, then the reason for the differential improvement in recall is clear. One factor that could have contributed to the results is the length of the interstimulus interval. As mentioned previously, research has shown that blank spaces of as little as .8 seconds in massed practice tends to improve recall compared to uninterrupted presentations (Hintzman, et al., 1975). Toppino and DiGeorge, however, did not report the length of the interitem interval in their study.

On the other hand, it could be argued that massed practice supressed recall for 1st graders relative to preschoolers. But, given the above evidence this is an unlikely explanation. In either case, it is not possible to determine exactly from Toppino and DiGeorge's data which alternative is correct. Their conclusion, however, that preschoolers do not benefit from spaced repetitions compared to older children should be viewed with caution. It is always risky to accept an unreplicated null hypothesis, especially when the phenomenon under investigation is as robust and general as the spacing effect. Moreover, whatever evidence there is regarding developmental factors in the emergence of the spacing effect rests at the moment on a small sample in this one study. One final point to note was that Toppino and DiGeorge used two levels of spacing, lag 0 and lag 3. It would be of some important theoretical interest to determine the comparative effect on recall of some intermediate level of spacing, such as lag 1, with this younger population.

The present research, to be described in the next chapter, addressed the above methodological problems, attempted to discover the developmental course of the spacing effect, and in addition, tried to provide evidence in support of the retrieval operations hypothesis.

CHAPTER III

Two separate but related experiments were carried out in the present study. The first was a replication (with several modifications) of Toppino & DiGeorge's (1984) study in order (1), to correct some of their methodological problems and (2), to verify their claim that the spacing effect emerges with development. The second experiment focused on the effect on recall of very brief spacings with no intervening items between presentations. The hypothesis was that with subjects who do not rehearse, a blank interval between presentations is sufficient to induce a retrieval operation. If the probability of the occurrence of a retrieval operation increases with the length of the interval, then a spacing effect with blank intervals should be obtained.

Experiment 1

The main purpose of this experiment was to verify Toppino & DiGeorges's (1984) conclusion that the spacing effect emerges with development. A number of modifications were implemented in order to eliminate as far as possible methodological problems involved in Toppino and DiGeorge's study.

(1) More precise control over presentation of stimulus material was required. Thus, instead of manual presentation, a

rearview screen projector with both audio and visual modes of presentation was used. Presentation duration of the items was precisely timed by electronic cue pulses on an audio tape that controlled both auditory and visual presentation (see below).

(2) Word lists, in addition to picture lists were also included in order to address a number of questions raised by Toppino and DiGeorge's study. (see above discussion).

(3) A wider age range of subjects was used. In addition to the two age groups used by Toppino & DiGeorge (i.e., preschool and 1st grade), two additional groups (i.e., kindergarten and grade 3 children) were included in the present study. This was done in order to map more precisely the developmental course of the spacing effect.

(4) Toppino and DiGeorge compared three conditions in their study, a once presented item (1P), and two levels of spacing (0 and 3). In the present experiment in addition to the 1P items, three levels of spacing were compared (lag 0, 1, and 3).

(5) A slightly larger number of subjects (24 versus 18) was used in each of the four age groups in both experiments in the present study.

Method

Subjects: The subjects were 96 children, 24 each from four age groups: preschool (average age 4.00 years), kindergarten (average age 5.40 years), 1st grade (average age 6.46 years) and 3rd grade (average age 8.33 years). Approximately half the children were male and half were female and all were from a local preschool and elementary school.

Design: The design was 4 X 2 X 4 factorial involving the comparison of four age groups (preschool, kindergarten, 1st grade, and 3rd grade) using two types of material (words and pictures) and four different levels of spacing (1P, 0, 1 and 3 intervening items). Age was a between subject variable and material and spacing were within subject variables. A two minute oral free-recall test was given immediately after presentation of the last item in each list.

Materials and apparatus: The words which were one or two syllable concrete nouns were taken from a spoken word count (children ages 5, 6, and 7) developed by Wepman and Hass (1969). They were typed in capital letters on a white background using a block type face (Helvetica), photographed with a close-up lens and developed as 35mm slides. Pictures, corresponding to the words, were black line drawings on a white background (after Snodgrass & Vanderwart, 1980) and were similarly made into slides (see Appendix A for samples of words and pictures). The slides were presented audio-visually to the subjects on a Bell and Howell rearview screen projector (Model 797). The presentation of slides was controlled by an electronic cue pulse on one track of an audio cassette tape. Duration of each slide was 5 seconds and slide onset was accompanied by an audio presentation of the item (female voice) recorded on the other track of the tape. Blank time between slides was 1.1 seconds. The size of the screen was 24 cm by 24 cm and the height of the letters in the words was 2.5 cm. The pictures were proportioned according to guidelines recommended by Snodgrass and Vanderwart (1980) and varied in size from approximately 18 cm X 14 cm to 13 cm X 9 cm.

For each type of stimulus material (words and pictures) sixteen lists were constructed. Each list consisted of 16 positions. The first two and last three of these positions were reserved for primacy and recency buffers, respectively. The middle portion of each list consisted of 11 positions. Six of these were taken by 3 items presented twice; one item had lag 0 (there were no intervening items between presentations), one had lag 1 (one intervening item), and one had lag 3 (three intervening items). One position was taken by a once presented item (1P). The remaining four positions were occupied by filler items. To ensure that any given item would serve in all four presentation conditions (i.e., 1P, 0, 1, and 3) and that each item was equally represented in all positions in the lists, a Greco-Latin square principle was used to counterbalance the items and conditions across all lists (see Appendix B for the complete design). Eight separate list sequences were constructed with each sequence containing two lists of words (W) and two lists of pictures (P). (See Appendix C for complete sequences). In every group three subjects each received one of the eight sequences. Half the subjects received a W,P,W,P order and half received P,W,P,W order.

Procedure: The subjects were seen individually and each child was presented with a sequence containing two lists of words and two lists of pictures. A standard set of instructions (see Appendix D) was given verbally to each subject, followed by a brief practice session. When it was clear that the child understood the task the experimental lists were presented. As each word or picture was presented audio-visually the subject was required to verbalize that item aloud. Following the presentation of each list a two minute oral free-recall was given and responses were tape recorded for later analysis. If a child stopped responding during the recall period before the two minutes had elapsed, two prompts were used. The first of these was 'Try really hard and see if you can think of any more words/pictures' and the second was 'You still have some time left, can you think of any more words/pictures?' If the child could not remember any other items shortly after the second prompt then the next list was presented, and so on.

Results

Subjects received 2 word lists and 2 picture lists and each list contained 1 item at each of the four spacing conditions. In each condition, therefore, a child could obtain a score of 0, 1, or 2 for each type of material (words or pictures), depending on whether s/he recalled zero, one or both critical items. These scores were the dependent variable for all analyses. Mean recall scores and standard deviations as a function of age, spacing, and type of material are summarized in Table 2. Figure 1 shows the spacing function for each age group with words and pictures combined.

A preliminary analysis of variance showed that recall of twice presented items with 0 spacing (mean = .79) was better than recall of once presented items (mean = .52), [$F(1,92) = 13.95$, $p < .0003$]. Since the spacing function was of main interest a 4 (age) X 3 (spacing) X 2 (material) analysis of variance was carried out (see appendix E for complete ANOVA). All three main effects were significant. There were no significant interactions.

There was a main affect of age [$F(3,92) = 10.93$, $p < .0001$]. Overall recall increased with age with mean recall of .78, .92, 1.01, 1.25, for preschool, kindergarten, 1st grade and 3rd grade, respectively. There was a significant main effect of spacing [$F(2,184) = 12.49$, $p < .0001$]. The overall mean recall as a function of lags 0, 1, and 3 for words were .65, .87, .93, and for pictures were .93, 1.29, and 1.29, respectively. There was also a main effect of type of material [$F(1,92) = 35.18$, $p < .001$]. Pictures (mean = 1.02) were recalled better than words (mean = .73).

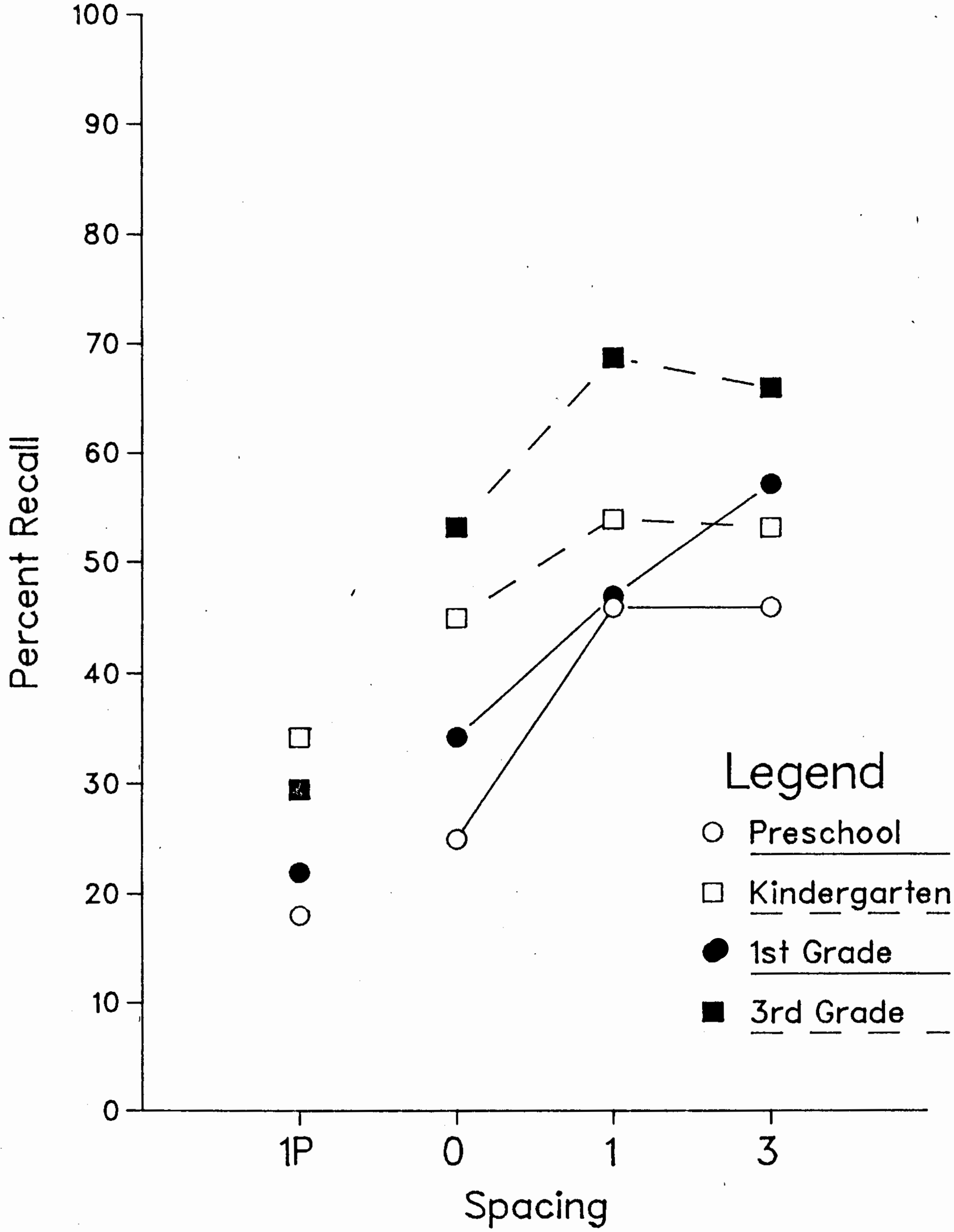
Planned comparisons showed that retention increased as a function of spacing for lags 0 to 1 [$F(1,92) = 17.62$, $p < .0001$]

TABLE 2

Mean number of items recalled (M) and Standard Deviations (SD) as a function of once presented items (1P) or repeated items (0, 1, or 3 intervening items) for each age group (preschool, kindergarten, 1st grade, 3rd grade) in Experiment 1.

	WORDS				PICTURES			
Group 1 (preschool)								
	1P	0	1	3	1P	0	1	3
M	.33	.38	.63	.71	.38	.63	1.21	1.13
SD	.56	.65	.65	.55	.65	.65	.59	.61
Group 2 (Kindergarten)								
M	.58	.67	.83	.96	.79	1.13	1.33	1.17
SD	.72	.70	.64	.62	.66	.68	.70	.76
Group 3 (1st grade)								
M	.38	.58	.71	.92	.50	.79	1.17	1.38
SD	.49	.65	.69	.78	.51	.72	.64	.71
Group 4 (3rd grade)								
M	.58	.96	1.29	1.13	.58	1.17	1.46	1.50
SD	.72	.75	.69	.74	.65	.76	.72	.59

Figure 1
Percent recall as a function of spacing (0,1, or 3 intervening items) and once presented items (1P) for words and pictures combined in Experiment 1



but not for lags 1 to 3 [$F(1,92) = .23$]. Comparisons between age groups showed grade three children recalled more than the other three age groups [$F(1,94) = 23.40$, $p < .0001$]. Kindergarten and grade one children were not significantly different from each other, [$F(1,46) = 1.04$] but both recalled more than preschoolers [$F(1,70) = 6.38$, $p < .01$].

Discussion

The data from this experiment do not confirm Toppino & DiGeorge's (1984) findings. The present results contradict their assertion that the spacing effect emerges with development. Preschoolers, as well as older children, benefited from repetitions that were spaced rather than massed.

The results of Experiment 1 suggest that the beneficial effects of spacing asymptotes at lag 1 and does not continue to improve beyond this point. Thus, it would appear that the spacing effect with young children (preschool to grade 3) is a function of very short spacing (i.e., up to 5 seconds). Furthermore, the spacing effect can be obtained with two types of material, words and pictures, with this age group. This suggests that whatever mechanism is involved in the spacing effect it is not differentially effective with words and pictures.

The results of Experiment 1 pose problems for the rehearsal hypothesis in its original formulation. Children up to grade 3 do not typically engage in spontaneous rehearsal (Ornstein &

Naus, 1978) and if they do, they generally rehearse one item at a time and only the most recently presented item (e.g., Ornstein, Naus & Liberty, 1975; Ornstein, Naus & Stone, 1977). Thus, if rehearsal between P1 and P2 is assumed to underlie the spacing effect there should be no spacing effect for this population. It would appear from the present data that better recall for spaced vs. massed practice items cannot be accounted for by additional rehearsal of the spaced items. The fact that the spacing effect was demonstrated with children as young as 4 years of age, suggests that some automatic process that does not rely on voluntary control processes could be involved.

The hypothesis proposed here, is that the occurrence of a retrieval operation is a sufficient condition for the spacing effect to occur and that the probability of this operation increases with spacing. Further support for this hypothesis could be obtained if it were shown that a spacing effect could be demonstrated with the use of <u>blank</u> intervals between repetitions of items with a population of subjects who do not rehearse.

The results of Experiment 1 indicated that there was an increased probability of recall with blank spacings of only 1.1 seconds (lag 0) compared to once presented items. Moreover, retention was further facilitated by spacings of up to 5 seconds (one intervening item), but not beyond this point. These results point to the importance of very brief intervals in investigating the spacing effect in young children.

Consider the following. If an item is presented twice, but with the spacing between presentations so brief that there is no discernible interstimulus interval, then the two presentations can be considered to be a true massed condition. In other words, true lag 0 can be defined as no interruption between P1 and P2. Conditions that involve spacings between repetitions, however brief, can be considered as distributed. Manipulations of this variable should help in specifying more precisely the locus of the spacing effect. It is also hypothesized that brief spacings using blank intervals, with subjects who do not engage in rehearsal or other memorial strategies, will provide evidence for the occurrence of retrieval operations. In order to investigate these notions Experiment 2 was implemented.

Experiment 2

Method

Subjects: The subjects were 96 children, 24 each from four age groups: preschool (average 4.27 years), kindergarten (average age 5.47 years), 1st grade (average age 6.45 years), and 3rd grade (average age 8.60 years). Approximately half the children were male and half were female and all were from a local preschool and elementary school.(These schools were different from those of Experiment 1, but were considered equivalent in terms of socio-economic status).

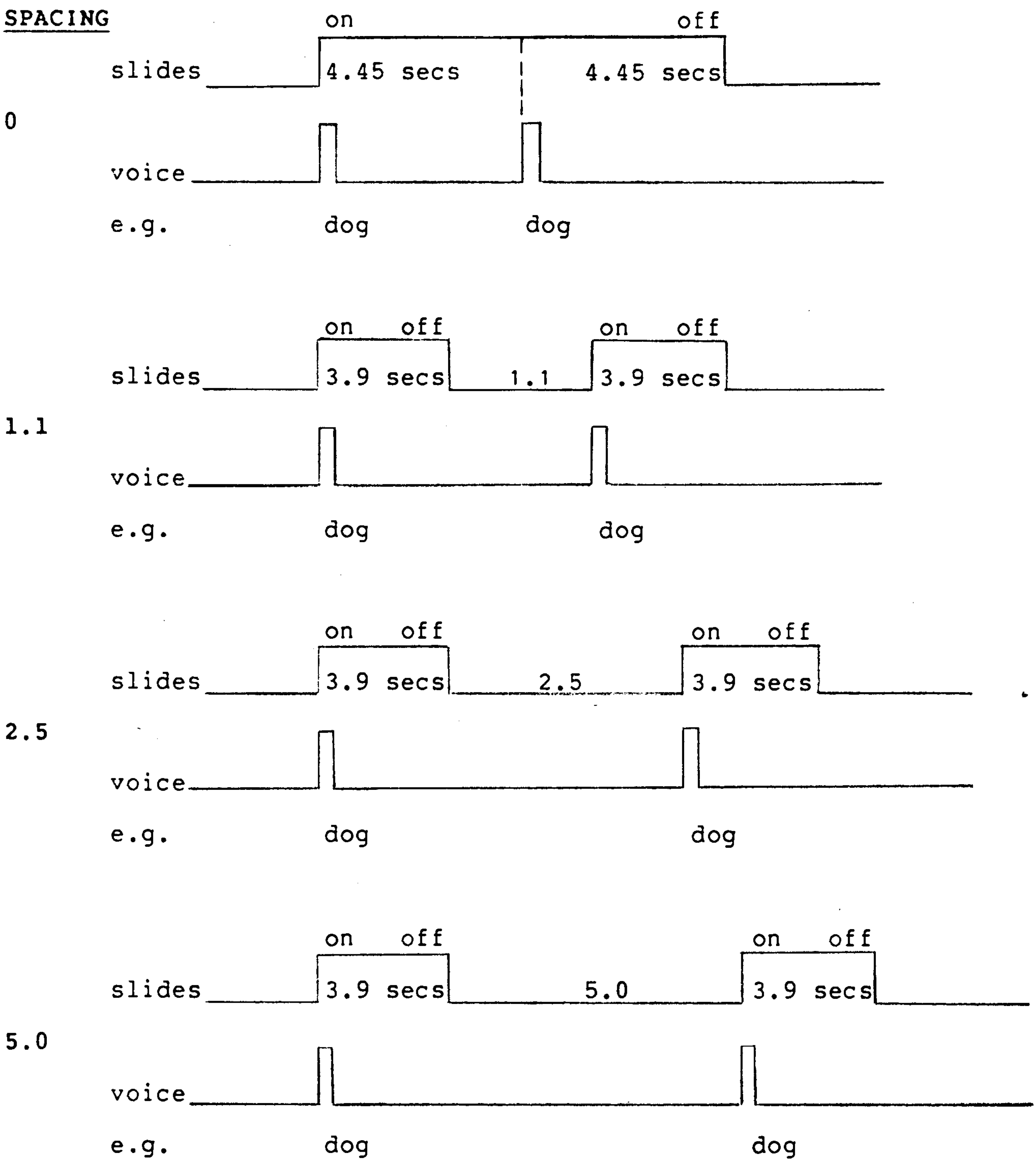
Design: The design was a 4 X 2 X 4 factorial involving the comparison of four age groups (preschool, kindergarten, 1st grade, and 3rd grade) using two types of material (words and pictures) and 4 levels of spacing (0 seconds, 1.1 seconds, 2.5 seconds, and 5 seconds). Age was a between subject variable while material and spacing were within subject variables.

Materials and apparatus: The stimulus materials and apparatus were the same as those used in Experiment 1. A computer program was developed which controlled the recording of electronic cue pulses on one track of the cassette tape for the various spacings required. Thus, very precise control over the interstimulus interval between repeated items and slide presentations was obtained. The corresponding audio presentation of each item was recorded on the other track using a female voice. The sequence of events in each of the four spacing conditions is summarized in Figure 2. For the 0 spacing condition the slide was exposed without interruption for a total of 8.9 seconds, conceptualized as 2 visual presentations of 4.45 seconds each, with a 0 time interval between them. The visual presentation at 0 spacing was accompanied by two repeated audio presentations of the picture shown (e.g., dog), one coinciding with slide onset, the other occurring at 4.45 seconds, i.e., in the middle of the visual exposure interval.

For the 1.1 spacing condition, the first presentation of the slide (P1) had a duration of 3.9 seconds. This was followed by a blank interval of 1.1 seconds, and then the second presentation

FIGURE 2

Sequence of events in each of the four spacing conditions in Experiment 2.



of the slide occurred (P2), which was also 3.9 seconds duration. Voice onset was coordinated with the onset of each slide. Total time from onset of P1 to the offset of P2 was 8.9 seconds, the same total time lapse between slide onset and offset as used in the 0 spacing condition. Notice that lag 1.1 corresponds to a <u>nominal</u> zero condition. That is, two <u>nominally</u> immediate successive slide presentations are actually separated by a projector slide change in the order of approximately one second, depending on the equipment being used. In the present case the actual blank out time during the slide change was exactly 1.1 seconds. This is the reason that lag 1.1 with a 1.1 second interstimulus interval was chosen as the shortest possible interrupted stimulus condition.

For the spacing conditions of lag 2.5 and lag 5.0, the blank time between P1 slide offset and P2 slide onset, was 2.5 seconds and 5 seconds, respectively. Audio presentation accompanied onset of each slide.

For each type of stimulus material (words or pictures) sixteen lists were constructed each of 17 positions. The first two and last three positions were reserved for primacy and recency buffers, respectively. Eight of the 12 middle positions were taken by four items presented twice; one each at spacings of 0, 1.1, 2.5, and 5 seconds. Two positions were taken by once presented items (1P), and two by blank slides. (see appendix F for complete sequences of words and pictures). In order that the same set of items serve in all four spacing conditions and that each item be equally represented in all positions in the lists, a Greco-Latin square principle was used to counterbalance the items and conditions across all lists (see Appendix G for the complete design). The two 1P items in each list were randomly selected from the filler items used in Experiment 1. Eight separate sequences were constructed with each sequence containing two lists of words (W) and two lists of pictures (P). In every age group three subjects each received one of the eight sequences. Half received W,P,W,P order and half received P,W,P,W order.

Procedure: The subjects were seen individually and each child was presented with a sequence containing two lists of words and two lists of pictures. A standard set of instructions (see Appendix D) was given verbally to each subject, followed by a brief practice session. When it was clear that the child understood the task, the experimental lists were presented. As each word or picture was presented audio-visually the subject was required to verbalize the items aloud. Following the presentation of each list a two minute oral free-recall was given and responses were tape recorded for later analysis. During the recall period, if a child stopped responding, two prompts identical to those used in Experiment 1 were used.

Results

Subjects received 2 word lists and 2 picture lists and each list contained 1 item at each of the four spacing conditions.

For each condition, therefore, a child could obtain a score of 0, 1, or 2 for each type of material (words or pictures), depending on whether s/he recalled zero, one or both critical items. These scores were the dependent variable for all analyses. Mean scores and standard deviations as a function of age, spacing, (including 1P) and type of material are summarized in Table 3. Figure 3 shows the spacing function for each age group with words and pictures combined.

In order to examine the spacing function, a 4 (age) X 4 (spacing) X 2 (material) analysis of variance was carried out. (see Appendix H for the complete ANOVA).

There was a main effect of age [$F(3,92) = 13.62$, $p < .0001$]. Recall increased with age with means of .72, .83, .79, and 1.14 for preschool, kindergarten, 1st and 3rd grade, respectively. There was a significant main effect of spacing [$F(3,276) = 10.81$, $p < .0001$]. Mean recall for spacings of 0, 1.1, 2.5, and 5 seconds was .59, .71, .62, .88 for words, and .76, 1.06, 1.07, and 1.25 for pictures, respectively. There was also a significant main effect for type of material [$F(1,92) = 40.94$, $p < .0001$]. Pictures (mean = 1.04) were recalled better than words (mean = .70). There were no significant interactions.

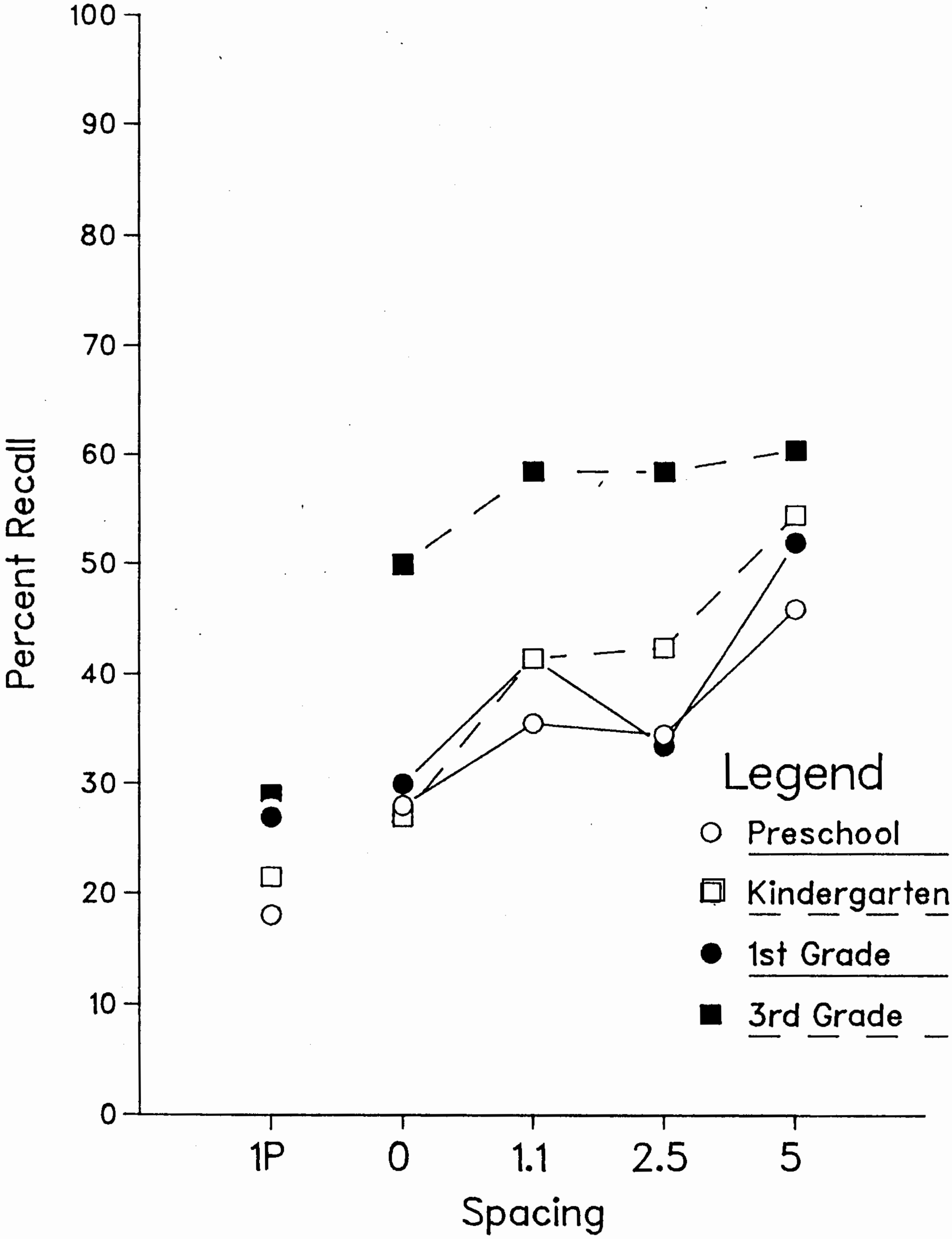
Further planned comparisons showed that recall improved from the 0 to the 1.1 second spacing [$F(1,92) = 10.22$, $p < .002$] and from the 2.5 to the 5 second spacings [$F(1,92) = 10.05$, $p < .002$] but that the spacing function levelled off between the 1.1

TABLE 3

Mean number of items recalled (M) and Standard Deviations (SD) as a function of once presented items (1P) or repeated items at spacings of 0, 1.1, 2.5, or 5 seconds for each age group (preschool, kindergarten, 1st grade, 3rd grade) in Experiment 2.

	WORDS					PICTURES				
	1P	0	1.1	2.5	5	1P	0	1.1	2.5	5
Group 1 (preschool)										
M	.38	.50	.67	.46	.83	.33	.63	.75	.92	1.00
SD	.42	.59	.76	.59	.76	.28	.58	.74	.83	.78
Group 2 (kindergarten)										
M	.44	.50	.54	.67	.75	.42	.58	1.13	1.04	1.42
SD	.45	.66	.59	.70	.68	.43	.72	.74	.69	.65
Group 3 (1st grade)										
M	.50	.58	.58	.33	.88	.58	.63	1.08	1.00	1.21
SD	.36	.65	.58	.56	.68	.41	.77	.83	.66	.66
Group 4 (3rd grade)										
M	.52	.79	1.04	1.00	1.04	.65	1.21	1.29	1.33	1.38
SD	.52	.66	.69	.66	.69	.40	.59	.75	.64	.82

Figure 3
Percent recall as a function of spacing (0, 1.1, 2.5, or 5 secs.) and once presented items (1P) for words and pictures combined in Experiment 2



and 2.5 spacing [$F(1,92) = .36$].

Although 1P items had not been completely counterbalanced with the repeated items, a comparison between their recall and that of items repeated at the 0 spacing was of some interest. An analysis of variance showed that recall was greater for lag 0 items than 1P items [$F(1,92) = 39.76$, $p < .0001$].

Other analyses showed that preschoolers, kindergarten and grade 1 were not significantly different in their levels of recall (overall means .72, .83, .79, respectively), [$F(1,69) = 1.35$]. Grade 3, (mean = 1.14) however, was significantly different from the other three age groups. [$F(1,92) = 38.23$, $p < .0001$].

Discussion

The results of Experiment 2 illustrated a number of important points. First, these data provide further evidence that preschoolers, as well as older children, can benefit from spaced repetitions compared to massed repetitions. Second, spacings as short as 1.1 seconds can improve recall compared to 0 seconds with this population. Third, spacings of up to 5 seconds between repetitions would appear to be optimal in producing the spacing effect in young children. Fourth, the results of Experiment 2 add support to Hintzman and Roger's (1973) claim that rehearsal is not a necessary condition for producing the spacing effect. Fifth, the present results also point to a possible explanation for Toppino & DiGeorge's (1984) failure to obtain a spacing with preschoolers compared to 1st grade. Although these authors did not report the length of the interstimulus interval (ISI) between presentations in either the massed or distributed practice conditions, the impreciseness of manual presentation of the visual material may have led to variations in the interstimulus interval. It is noteworthy that in their data there was an equivalent level of recall for massed items for both preschoolers and 1st graders (34.7% and 37.5%, respectively). If the ISI for 1st graders was relatively brief (i.e., close to 0 seconds) in this condition, and because of greater distractibility or other factors, the ISI for preschoolers was somewhat longer (i.e., up 1.1 seconds), then, based on the present data, there should be enhanced recall for the preschooler to approximately that of the 1st graders. An analysis of the present data showed that preschoolers recalled 30.5% of items spaced at 1.1 seconds and 1st graders recalled an equivalent 30% for items with a 0 interval between repetitions. While this is an admittedly speculative post hoc analysis of Toppino & DiGeorge's data it is at least plausible in terms of the results of Experiment 2.

CHAPTER IV

General Discussion

Both experiments in the present study have shown that, contrary to Toppino & DiGeorge's (1984) results, children as young as 4 years of age can benefit from spaced repetitions. Moreover, the spacing function was found to be the same across all groups, ranging from approximately 4 to 9 years of age. These results are consistent with those of other researchers who have demonstrated the spacing effect with children (e.g., Toppino & DiGeorge, 1984; Toppino & DeMesquita, 1984; Wilson, 1976).

Experiment 1 of the present study demonstrated the spacing effect at the shortest lag tested (i.e., lag 1, or one intervening item). Experiment 2 has shown that a spacing effect could be obtained with the present population using very short blank spacings. In sum, the present study indicated the existence of the spacing effect in children 4 to 9 years old, both when other items intervene between successive presentations of target items (Experiment 1), as well as when only a blank interval intervenes (Experiment 2).

Theoretically, the hypothesis which motivated the present research was that retrieval operations are sufficient for the spacing effect to occur. This hypothesis was investigated by using young children on the assumption that they do not use mnemonic strategies, as adults normally do. The hypothesis was supported, in particular, by the results of Experiment 2 where it was demonstrated that blank spacings as short as 1.1 seconds were sufficient to produce the distributed practice effect compared to 0 spacing. The relevance of this finding will become clear when the present results are discussed in terms of other theories of the spacing effect.

It may be useful for this discussion to recapitulate the two major categories of theory that have been formulated to account for this phenomenon. First, deficient processing theories assume that when items are massed, either P1 or P2 is not fully processed. With increased spacing however, the probability of further processing of either one or both presentations increases and better recall will result. This beneficial processing is assumed to be either voluntary (rehearsal or attention) or involuntary (consolidation or habituation). Second, encoding variability theories propose that repetition facilitates memory to the extent that each presentation is encoded differently and thus provides more retrieval routes to the information during the recall test. When items are spaced apart both items are assumed to be differentially encoded, whereas when they are massed they are more likely to be similarly encoded. Consequently, better recall will result during a recall test with the former compared to the later.

Consider first one of the major deficient processing theories, the rehearsal hypothesis. This hypothesis would seem to be least compatible with the present results. First, the age range of the population tested in both Experiment 1 and Experiment 2 have been shown to typically not engage in spontaneous rehearsal (Ornstein & Naus, 1977). Yet, across both experiments the spacing effect was obtained. Further, if rehearsal were a factor, one would predict that in Experiment 1 recall would tend to improve between 1 and 3 intervening items. However, this was not the case. It is true that rehearsal, as a possible mechanism, cannot be discounted as contributing to the spacing effect in older populations. The present results indicate, however, that at a minimum, rehearsal is not necessary to account for the spacing effect. This adds support to the findings of other researchers who found no evidence for rehearsal as an explanation of the spacing effect (e.g., Hintzman & Rogers, 1973).

A second deficient processing explanation of the spacing effect suggests that subjects adopt a voluntary strategy in which they do not attend to and fully process the second presentation of an item when it is massed, but that they devote more attention to P2 as spacing increases. As noted earlier, attention has, in general, not been clearly operationally defined in experiments investigating the spacing effect. Attention, however defined, is a necessary condition for the spacing effect (i.e., the subject must attend to the items) but this alone may not be a sufficient explanation. For example, consider the isolation or Von-Restorff effect, where an item that is distinctive in a list is generally recalled better than other items in a serial learning task. In Experiment 2 an item repeated at lag 0 (with no interruption between P1 and P2) was distinctly different from the items repeated with blank items between repetitions (spacings of 1.1, 2.5, and 5), yet recall for these items was less than for the other conditions. One would expect more attention to be paid to lag 0 items and thus, if the attention hypothesis were correct better recall should have resulted.

If the distinction between voluntary and involuntary processes is dropped then one may consider some kind of involuntary or automatic attentional process as being involved in the spacing effect. The habituation hypothesis proposes such an automatic process. According to this hypothesis after the first presentation of an item (P1), the mechanism responsible for encoding that item is engaged for a period of time (i.e., it continues to habituate) and will not be able to respond to P2 until sufficient time has passed for recovery from that process to take place. When P2 is spaced apart from P1, recovery from habituation is complete by the time P2 occurs, and better recall is predicted compared with massed practice where P2 occurs before recovery is complete (Hintzman, 1974).

One problem with this hypothesis, however, is that the time course for recovery from habituation is not clearly specificed. Hintzman, et al., (1975) demonstrated that recovery was not affected by duration time of the stimulus. Various exposure times of the stimuli (i.e., 2.2, 5.2 or 8.2 seconds) produced almost identical spacing functions. In the present study (Experiment 2) a blank interval between P1 and P2 of 1.1 seconds following the 3.9 duration exposure produced greater recall than 0 spacing. If habituation is involved then recovery from processing P1 would have to take less time than 1.1, seconds which would seem to be implausible. Moreover, in Experiment 2 a longer blank interval of 2.5 seconds between P1 and P2 did not improve recall relative to a 1.1 second interval, but recall did significantly improve with a spacing of 5 seconds. The habituation hypothesis cannot account for these findings.

The consolidation hypothesis, on the other hand, suggests that deficient processing results because, when P1 and P2 are contiguous, the amount of consolidation produced by both items together will be less than if P2 is delayed until consolidation of P1 is complete (Landauer, 1969, 1974). The locus of the consolidation processing according to Hintzman (1976) is between P1 and P2. A major problem for this theory, similar to one raised in connection with the habituation hypothesis, is that the time taken for consolidation to occur has not been clearly determined. It has been estimated to range from 15 seconds to more than an hour (Baddeley, 1976). The fact that the spacing effect was obtained with very short spacings in the present study poses problems for this hypothesis. If the hypothesized mechanisms of habituation or consolidation are involved in the spacing effect, previous research has not been very successful demonstrating their operations (e.g., Cornell, 1980; Hintzman et al., 1975). Similarly, the results of the present study offers little support for their existence and involvement in the spacing effect.

Consider next a number of theories that involve encoding variability as an explanatory mechanism for the spacing effect (e.g., Glenberg, 1979; McFarland, Rhodes, & Frey, 1979). These theories are not precise regarding the voluntary or involuntary nature of the mechanisms involved but, in general, all agree that as spacing increases the probability of successful retrieval also increases because of differential encoding of information at P1 and P2. This position assumes that as the spacing between repeated items increases, the probabilty that a repeated item is grouped with different items also increases, and consequently there will be greater independence between P1 and P2 (i.e., less overlap). Thus, differential encoding as a function of increased spacing is hypothesized to be the mechanism underlying the spacing effect.

In Experiment 2, items that were repeated at spacings of 1.1, 2.5, or 5 seconds, were always associated with blank intervals. This factor should tend to produce constant encoding of all repeated items with blank intervals and thus there should be equivalent recall for these conditions. This, however, was not the case. Moreover, with the particular design used in the present study, the items in all 4 spacing conditions in Experiment 2 were equivalent in the probability of their being associated with other items. Thus, according to the encoding variability hypothesis, there should have been no increase in retention as a function of spacing because spacing did not involve greater encoding variability. The opposite, however, was found to be the case. The present study, as well as previous research (e.g, Bird, Nicholson, & Ringer, 1978; Maskarinec & Thompson, 1976; Postman & Knecht, 1983; Toppino & Gracen, 1985; Young & Bellezza, 1982) fail to support some obvious predictions from the encoding variability class of theories. In addition, other studies with children (e.g., Toppino & DeMesquita, 1984) failed to find support for the encoding variability theory.

A final class of theory to be considered here, and one which is perhaps more compatible with the present data, is derived from the levels-of-processing point of view (Craik & Lockhart, 1972). Various formulations which have this theme in common have been proposed (e.g., Jacoby, 1978; Rose & Rowe, 1976). The basic notion implicit in these explanations is that when items are massed, the subject need not process the second presentation to the same extent as the first because it is easily contacted in recent episodic memory. Thus, relatively less processing effort is required at P2. As spacing increases between P1 and P2 more effort than mere scanning must be engaged in and the subject must reconstruct or repeat the processing used at P1. This reconstruction process is assumed to involve a deeper level of processing than mere scanning and consequently later retention will be enhanced.

The data from Experiment 1 can be nicely accounted for by this hypothesis. The fact that retention was greater for lags 1 and 3, than lag 0 can be accounted for because with longer lags more reconstructive processing effort was required.

Likewise with the data from Experiment 2, items with a true 0 spacing between repetitions would require less processing effort than would items with even a short spacing between repetitions. As the spacing increases between items (up to 5 seconds) more processing effort is required and consequently better recall will result. Thus the reconstruction, or effort theories, of Jacoby (1978) and Rose (1984) are supported by the present data. As noted previously, there is a great deal of similarity between the reconstruction theory and the retrieval operations hypothesis. It would appear that both positions can account for the results of the present study. In fact, it may be that the only difference between the reconstruction and retrieval operation hypotheses is one of degree or emphasis, rather than kind. As pointed out earlier, the idea of a retrieval operation is preferred here because it is not clear what kind of "reconstructing" is involved at the second presentation of an item. All one can say is that what seems necessary is for the second presentation to retrieve the first. The discovery of the exact nature of this mechanism is left for future research.

Implications

The results of the present study suggest a number of possibilities for research as well as implications for practical applications.

There is a substantial body of literature concerned with the effect of tests on later retention (e.g., Izawa, 1971; Landauer & Eldridge, 1967; Whitten & Leonard, 1980). The paradigm typically used includes a single presentation followed by a series of tests. It has been clearly demonstrated that test trials increase memory performance as measured in later retention tests (e.g., Modigliani, 1976, 1978, 1980; Runquist, 1983; Wenger, Thomson & Bartling, 1980; Whitten & Bjork, 1977). The results of this body of research suggests a possible way to test the retrieval operations hypothesis. This would involve using a paradigm in which the critical sequence of events was not two presentations (P1 and P2) followed by a test (T), as was the case in Experiment 1 and 2, but rather P1, T1, and then T2. The critical variable would be the P1 - T1 interval. If the P1 - T1 interval were blank, and assuming again that young children do not rehearse, then a successful recall at T1 would imply a retrieval operation. If, as suggested previously, the probability of a retrieval operation increases with the length of the interval, then a spacing effect with tests should also be obtained.

Using similar reasoning, it might be worthwhile to repeat Experiment 2 with adults but using longer lists in order to preclude ceiling effects. It would be of interest to discover if the interrupted stimulus effect found with children would also be evident in more sophisticated learners. Indications that this is possible have been provided by a previously mentioned incidental finding by Hintzman, Summers and Block (1975; see also Nelson, 1977, Experiment 1).

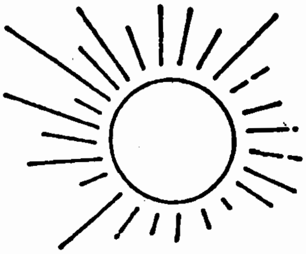
With regard to practical applications it might be imagined that with a phenomenon as ubiquitous as the spacing effect, there would be a great number of empirical investigations in applied settings. This, however, is not the case. A review of the literature produced very few studies in which this robust phenomenon has been utilized to promote learning in educational or real life settings (e.g., Bloom & Shuell, 1981; Di Vesta & Smith, 1979; Rea & Modigliani, 1985; Reder & Anderson, 1980, 1982; Reith, Axelrod, Anderson, Hathaway, Wood & Fitzgerald, 1974; Siegel & Misselt, 1984). One reason for the lack of practical investigations may be due to the fact that massed practice is a frequently used rehearsal strategy, and its effectiveness is often overestimated. Indeed, massed practice follows logically from the correct assumption that increased frequency of repetition improves retention. Repetitions, however, should be distributed to be most effective. Moreover, massed practice keeps the target item in mind while it is being rehearsed and, although it is not very effective compared to spaced practice for long term retention, it nevertheless results in greater confidence in being able to remember (Landauer & Ross, 1977). For example, in one study where teachers were asked to judge the instructional effectiveness of prose passages, they gave higher ratings to texts in which critical information was massed than to those where it was spaced, contrary to actual effectiveness (Rothkopf, 1963).

The results of the present study point to a simple way to increase the effectiveness of drill and practice in educational settings. With younger children at least, the effect of very short intervals between items would appear to enhance later recall. This would seem to be an important and easily manipulated variable to consider when structuring to-be-remembered material in typical classroom situations such as drill and practice sessions.

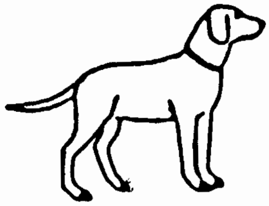
In addition, instructional computer software designed to teach young children various facts such as addition, multiplication, division, etc., could benefit from the incorporation of schedules of spaced practice (e.g., Siegal & Misselt, 1984). Programs of instruction based on empirical and theoretical findings can assist in the acquisition of knowledge and skills in an efficient and effective manner.

APPENDIX A

Samples of words and pictures used in Experiment 1 and 2.

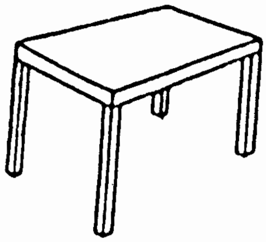


SUN

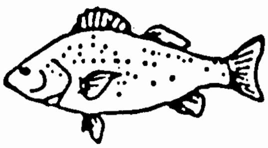


DOG

FOOT



TABLE



FISH

TOP

APPENDIX B

Greco-Latin Square design used to construct the 16 lists for Experiment 1. (see Appendix C for lists of actual words and pictures)

CODES: A to P = words(W)/pictures(P)
1 to 4 = spacing conditions
(1 = 1P, 2 = Lag 0, 3 = lag 1, 4 = lag 3)

LISTS:	1	2	3	4	5	6	7	8
	A1	B2	C3	D4	E1	F2	G3	H4
	D2	C1	B4	A3	H2	G1	F4	E3
	B3	A4	D1	C2	F3	E4	H1	G2
	C4	D3	A2	B1	G4	H3	E2	F1

LISTS:	9	10	11	12	13	14	15	16
	I1	J2	K3	L4	M1	N2	O3	P4
	L2	K1	J4	I3	P2	O1	N4	M3
	J3	I4	L1	K2	N3	M4	P1	O2
	K4	L3	I2	J1	O4	P3	M2	N1

SEQUENCES: (8 sequences constructed from the above 16 lists using both words(W) and pictures(P).

SEQUENCE 1:	1(W)	6(P)	11(W)	16(P)
SEQUENCE 2:	2(P)	7(W)	12(P)	13(W)
SEQUENCE 3:	3(W)	8(P)	9(W)	14(P)
SEQUENCE 4:	4(W)	5(P)	10(W)	15(P)
SEQUENCE 5:	16(W)	11(P)	6(W)	1(P)
SEQUENCE 6:	13(P)	12(W)	7(P)	2(W)
SEQUENCE 7:	14(W)	9(P)	8(W)	3(P)
SEQUENCE 8:	15(P)	10(W)	5(P)	4(W)

APPENDIX C

Word and Picture Lists Used in Experiement 1

Sequence 1

Words	Pictures	Words	Pictures
pipe	tomato	plane	mouse
lamp	snowman	apple	sheep
IP = fish	arm	tree	car
bus	0 = arm	finger	book
0 = bus	IP = truck	1 = tree	hand
hat	house	ear	hammer
eye	T.V.	leaf	3 = car
1 = hat	duck	bed	dog
leg	table	horse	bike
bear	3 = house	3 = ear	1 = dog
door	snake	sun	shoe
top	sock	cow	0 = shoe
3 = leg	1 = snake	0 = cow	1P = nose
barn	foot	bug	pig
bat	lion	ball	cup
clock	spoon	fly	shirt
?	?	?	?

Appendix C (cont'd)

Sequence 2

Pictures	Words	Pictures	Words
pipe	tomato	plane	mouse
lamp	snowman	apple	sheep
hat	truck	sun	1P = dog
0 = hat	T.V.	finger	car
1P = leg	1 = truck	leaf	0 = car
fish	arm	bed	nose
eye	duck	3 = sun	book
bear	table	cow	1 = nose
door	sock	horse	shoe
3 = fish	3 = arm	1 = cow	hand
bus	1P = snake	tree	hammer
top	house	0 = tree	bike
1 = bus	0 = house	1P = ear	3 = shoe
barn	foot	bug	pig
bat	lion	ball	cup
clock	spoon	fly	shirt
?	?	?	?

Appendix C (cont'd)

Sequence 3

Words	Pictures	Words	Pictures
pipe	tomato	plane	mouse
lamp	snowman	apple	sheep
leg	snake	1P = cow	nose
eye	T.V.	sun	0 = nose
1 = leg	duck	0 = sun	1P = shoe
hat	table	ear	dog
bear	3 = snake	finger	book
door	house	1 = ear	hand
top	sock	tree	hammer
3 = hat	1 = house	leaf	3 = dog
1P = bus	truck	bed	car
fish	0 = truck	horse	bike
0 = fish	1P = arm	3 = tree	1 = car
barn	foot	bug	pig
bat	lion	ball	cup
clock	spoon	fly	shirt
?	?	?	?

Appendix C (cont'd)

<u>Sequence 4</u>

Pictures	Words	Pictures	Words
pipe	tomato	plane	mouse
lamp	snowman	apple	sheep
bus	1P = house	ear	shoe
eye	snake	0 = ear	book
bear	0 = snake	1P = tree	1 = shoe
door	arm	cow	nose
3 = bus	T.V.	finger	hand
fish	1 = arm	leaf	hammer
top	truck	bed	bike
1 = fish	duck	3 = cow	3 = nose
leg	table	sun	1P = car
0 = leg	sock	horse	dog
1P = hat	3 = truck	1 = sun	0 = dog
barn	foot	bug	pig
bat	lion	ball	cup
clock	spoon	fly	shirt
?	?	?	?

Appendix C (cont'd)

Sequence 5

Words	Pictures	Words	Pictures
mouse	plane	tomato	pipe
sheep	apple	snowman	lamp
car	tree	arm	1P = fish
book	finger	0 = arm	bus
hand	1 = tree	1P = truck	0 = bus
hammer	ear	house	hat
3 = car	leaf	T.V.	eye
dog	bed	duck	1 = hat
bike	horse	table	leg
1 = dog	3 = ear	3 = house	bear
shoe	1P = sun	snake	door
0 = shoe	cow	sock	top
1P = nose	0 = cow	1 = snake	3 = leg
pig	bug	foot	barn
cup	ball	lion	bat
shirt	fly	spoon	clock
?	?	?	?

Appendix C (cont'd)

Sequence 6

Pictures	Words	Pictures	Words
mouse	plane	tomato	pipe
sheep	apple	snowman	lamp
1P = dog	sun	truck	hat
car	finger	T.V.	0 = hat
0 = car	leaf	1 = truck	1P = leg
nose	bed	arm	fish
book	3 = sun	duck	eye
1 = nose	cow	table	bear
shoe	horse	sock	door
hand	1 = cow	3 = arm	3 = fish
hammer	tree	1P = snake	bus
bike	0 = tree	house	top
3 = shoe	1P = ear	0 = house	1 = bus
pig	bug	foot	barn
cup	ball	lion	bat
shirt	fly	spoon	clock
?	?	?	?

Appendix C (cont'd)

<u>Sequence 7</u>

Words	Pictures	Words	Pictures
mouse	plane	tomato	pipe
sheep	apple	snowman	lamp
nose	1P = cow	snake	leg
0 = nose	sun	T.V.	eye
1P = shoe	0 = sun	duck	1 = leg
dog	ear	table	hat
book	finger	3 = snake	bear
hand	1 = ear	house	door
hammer	tree	sock	top
3 = dog	leaf	1 = house	3 = hat
car	bed	truck	1P = bus
bike	horse	0 = truck	fish
1 = car	3 = tree	1P = arm	0 = fish
pig	bug	foot	barn
cup	ball	lion	bat
shirt	fly	spoon	clock
?	?	?	?

Appendix C (cont'd)

<u>Sequence 8</u>

Pictures	Words	Pictures	Words
mouse	plane	tomato	pipe
sheep	apple	snowman	lamp
shoe	ear	1P = house	bus
book	0 = ear	snake	eye
1 = shoe	1P = tree	0 = snake	bear
nose	cow	arm	door
hand	finger	T.V.	3 = bus
hammer	leaf	1 = arm	fish
bike	bed	truck	top
3 = nose	3 = cow	duck	1 = fish
1P = car	sun	table	leg
dog	horse	sock	0 = leg
0 = dog	1 = sun	3 = truck	1P = hat
pig	bug	foot	barn
cup	ball	lion	bat
shirt	fly	spoon	clock
?	?	?	?

APPENDIX D

Standard set of instructions used in Experiment 1 and Experiment 2.

We are going to play a little memory game. I am going see how many words/pictures you can remember. You will see a word/picture on the screen, and when it appears you will also hear it, and I want you to repeat it aloud, O.K.? Now, I want you to try and remember as many words/pictures as you can because at the end I will want you to tell me what words you heard (what pictures you saw). There will be many words/pictures so just try to remember as many as you can, O.K.? First, we will do a practice session so you can see how easy it is.

APPENDIX E

Overall analysis of variance (ANOVA) of data in Experiment 1 as a function of age (preschool, kindergarten, 1st grade, 3rd grade), type of material (words or pictures), and spacing (0, 1, or 3).

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	P
Mean	566.04340	1	566.04340	1095.86	0.0000
Age	16.93576	3	5.64525	10.93	0.0000
Error	47.52083	92	0.51653		
Type	18.41840	1	18.41840	35.18	0.0000
T x A	0.58854	3	0.19618	0.37	0.7714
Error	48.15972	92	0.52348		
Spacing	12.18056	2	6.09028	12.49	0.0000
S x A	2.06944	6	0.34491	0.17	0.6443
Error	89.75000	184	0.48777		
T x S	0.51389	2	0.25694	0.68	0.5067
T x S x A	1.54167	6	0.25694	0.68	0.6640
Error	69.27778	184	0.37651		

APPENDIX F

Word and Picture Lists Used in Experiment 2

(X = blank slide)

Sequence 1

	Words		Pictures		Words		Pictures
	pipe		tomato		plane		mouse
	lamp		snowman		apple		sheep
1P =	top		arm		tree		car
	fish		X	1.1 =	tree		X
0 =	fish	2.5 =	arm	1P =	T.V.	5.0 =	car
1P =	bike		truck		ear		dog
	bus	0 =	truck		X	1.1 =	dog
	X		house	5.0 =	ear	1P =	sock
2.5 =	bus		X	1P =	door		shoe
	hat	5.0 =	house		sun		X
1.1 =	hat	1P =	book	0 =	sun	2.5 =	shoe
	leg		snake		cow	1P =	table
	X	1.1 =	snake		X		nose
5.0 =	leg	1P =	leaf	2.5 =	cow	0 =	nose
	barn		foot		bug		pig
	clock		lion		fly		cup
	bat		spoon		ball		shirt
	?		?		?		?

Appendix F (cont'd)

Sequence 2

Pictures	Words	Pictures	Words
pipe	tomato	plane	mouse
lamp	snowman	apple	sheep
hat	truck	1P = book	dog
X	1.1 = truck	sun	0 = dog
2.5 = hat	arm	X	car
1P = T.V.	X	5.0 = sun	X
leg	5.0 = arm	1P = leaf	2.5 = car
0 = leg	snake	cow	1P = sock
1P = door	0 = snake	1.1 = cow	nose
fish	1P = top	tree	1.1 = nose
X	house	X	1P = table
5.0 = fish	X	2.5 = tree	shoe
bus	2.5 = house	ear	X
1.1 = bus	1P = bike	0 = ear	5.0 = shoe
barn	foot	bug	pig
clock	lion	fly	cup
bat	spoon	ball	shirt
?	?	?	?

Appendix F (cont'd)

Sequence 3

Words	Pictures	Words	Pictures
pipe	tomato	plane	mouse
lamp	snowman	apple	sheep
leg	snake	1P = book	nose
1.1 = leg	X	cow	X
1P = sock	5.0 = snake	0 = cow	2.5 = nose
hat	house	1P = leaf	shoe
X	1.1 = house	sun	0 = shoe
5.0 = hat	1P = T.V.	X	dog
1P = table	truck	2.5 = sun	X
bus	X	ear	5.0 = dog
0 = bus	2.5 = truck	1.1 = ear	1P = top
fish	1P = door	tree	car
X	arm	X	1.1 = car
2.5 = fish	0 = arm	5.0 = tree	1P = bike
barn	foot	bug	pig
clock	lion	fly	cup
bat	spoon	ball	shirt
?	?	?	?

Appendix F (cont'd)

Sequence 4

Pictures	Words	Pictures	Words
pipe	tomato	plane	mouse
lamp	snowman	apple	sheep
1P = top	house	ear	shoe
bus	0 = house	X	1.1 = shoe
X	snake	2.5 = ear	nose
5.0 = bus	X	1P = sock	X
1P = bike	2.5 = snake	tree	5.0 = nose
fish	1P = T.V.	0 = tree	car
1.1 = fish	arm	1P = table	0 = car
leg	1.1 = arm	cow	1P = book
X	1P = door	X	dog
2.5 = leg	truck	5.0 = cow	X
hat	X	sun	2.5 = dog
0 = hat	5.0 = truck	1.1 = sun	1P = leaf
barn	foot	bug	pig
clock	lion	fly	cup
bat	spoon	ball	shirt
?	?	?	?

Appendix F (cont'd)

Sequence 5

Words	Pictures	Words	Pictures
mouse	plane	tomato	pipe
sheep	apple	snowman	lamp
1P = bike	tree	arm	fish
car	1.1 = tree	X	0 = fish
X	ear	2.5 = arm	bus
5.0 = car	X	door	X
1P = top	5.0 = ear	truck	2.5 = bus
dog	sun	0 = truck	1P = table
1.1 = dog	0 = sun	1P = T.V.	hat
shoe	1P = leaf	house	1.1 = hat
X	cow	X	1P = sock
2.5 = shoe	X	5.0 = house	leg
nose	2.5 = cow	snake	X
0 = nose	book	1.1 = snake	5.0 = leg
pig	bug	foot	barn
cup	fly	lion	clock
shirt	ball	spoon	bat
?	?	?	?

<u>Sequence 6</u>

Pictures	Words	Pictures	Words
mouse	plane	tomato	pipe
sheep	apple	snowman	lamp
1P = door	sun	truck	hat
dog	X	1.1 = truck	X
0 = dog	5.5 = sun	1P = bike	2.5 = hat
1P = T.V.	cow	arm	leg
car	1.1 = cow	X	0 = leg
X	1P = leaf	5.0 = arm	fish
2.5 = car	tree	1P = top	X
nose	X	snake	5.0 = fish
1.1 = nose	2.5 = tree	0 = snake	1P = table
shoe	1P = book	house	bus
X	ear	X	1.1 = bus
5.0 = shoe	0 = ear	2.5 = house	1P = sock
pig	bug	foot	barn
cup	fly	lion	clock
shirt	ball	spoon	bat
?	?	?	?

Appendix F (cont'd)

Sequence 7

Words	Pictures	Words	Pictures
mouse	plane	tomato	pipe
sheep	apple	snowman	lamp
nose	cow	1P = bike	leg
X	0 = cow	snake	1.1 = leg
2.5 = nose	sun	X	hat
1P = door	X	5.0 = snake	X
shoe	2.5 = sun	1P = top	5.0 = hat
0 = shoe	1P = table	house	bus
1P = T.V.	ear	1.1 = house	0 = bus
dog	1.1 = ear	truck	1P = leaf
X	1P = sock	X	fish
5.0 = dog	tree	2.5 = truck	X
car	X	arm	2.5 = fish
1.1 = car	5.0 = tree	0 = arm	1P = book
pig	bug	foot	barn
cup	fly	lion	clock
shirt	ball	spoon	bat
?	?	?	?

Appendix F (cont'd)

Sequence 8

Pictures	Words	Pictures	Words
mouse	plane	tomato	pipe
sheep	apple	snowman	lamp
shoe	ear	1P = door	bus
1.1 = shoe	X	house	X
1P = bike	2.5 = ear	0 = house	5.0 = bus
nose	tree	1P = T.V.	fish
X	0 = tree	snake	1.1 = fish
5.0 = nose	cow	X	1P = leaf
1P = top	X	2.5 = snake	leg
car	5.0 = cow	arm	X
0 = car	1P = table	1.1 = arm	2.5 = leg
dog	sun	truck	1P = book
X	1.1 = sun	X	hat
2.5 = dog	1P = sock	5.0 = truck	0 = hat
pig	bug	foot	barn
cup	fly	lion	clock
shirt	ball	spoon	bat
?	?	?	?

APPENDIX G

Greco-Latin Square design used to construct the 16 lists for Experiment 2. (see Appendix F for lists of actual words and pictures)

CODES: A to P = words(W)/pictures(P)
1 to 4 = spacing conditions
(1 = 0 secs., 2 = 1.1 secs., 3 = 2.5 secs., 4 = 5 secs.

LISTS:

1	2	3	4	5	6	7	8
A1	B2	C3	D4	E1	F2	G3	H4
D2	C1	B4	A3	H2	G1	F4	E3
B3	A4	D1	C2	F3	E4	H1	G2
C4	D3	A2	B1	G4	H3	E2	F1

LISTS:

9	10	11	12	13	14	15	16
I1	J2	K3	L4	M1	N2	P1	O2
L2	K1	J4	I3	P2	O1	N4	M3
J3	I4	L1	K2	N3	M4	P1	O2
K4	L3	I2	J1	O4	P3	M2	N1

SEQUENCES: 8 sequences constructed from the above 16 lists (including the once presented items (1P)), using both words(W) and pictures(P).

SEQUENCE 1

W	P	W	P
1P	F2	K3	P4
A1	G1	1P	M3
1P	E4	J4	1P
D2	1P	1P	O2
B3	H3	L1	1P
C4	1P	I2	N1

SEQUENCE 2

P	W	P	W
B2	G3	1P	M1
1P	F4	L4	P2
C1	H1	1P	1P
1P	1P	I3	N3
A4	E2	K2	1P
D3	1P	J1	O4

SEQUENCE 3

W	P	W	P
C3	H4	1P	N2
1P	E3	I1	O1
B4	1P	1P	M4
1P	G2	L2	1P
D1	1P	J3	P3
A2	F1	K4	1P

SEQUENCE 4

P	W	P	W
1P	E1	J2	03
D4	H2	1P	N4
1P	1P	K1	P1
A3	F3	1P	1P
C2	1P	I4	M2
B1	G4	L3	1P

SEQUENCE 5

W	P	W	P
1P	K3	F2	A1
P4	J4	1P	D2
1P	L1	G1	1P
M3	1P	1P	B3
O2	I2	E4	1P
N1	1P	H3	C4

SEQUENCE 6

P	W	P	W
1P	L4	G3	B2
M1	I3	1P	C1
1P	1P	F4	A4
P2	K2	1P	1P
N3	1P	HI	D3
O4	J1	E2	1P

SEQUENCE 7

W	P	W	P
N2	I1	1P	C3
1P	L2	H4	B4
O1	1P	1P	D1
1P	J3	E3	1P
M4	1P	G2	A2
P3	K4	F1	1P

SEQUENCE 8

P	W	P	W
D3	J2	1P	D4
1P	K1	E1	A3
N4	I4	1P	1P
1P	1P	H2	C2
P1	L3	F3	1P
M2	1P	G4	B1

APPENDIX H

Overall analysis of variance (ANOVA) of data in Experiment 2 as a function of age (preschool, kindergarten, 1st grade, 3rd grade), type of material (words or pictures), and spacing (0, 1.1, 2.5, 5 seconds).

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	P
Mean	577.54687	1	577.54687	1204.46	0.0000
Age	19.58854	3	6.52951	13.62	0.0000
Error	44.11458	92	0.47951		
Type	22.00521	1	22.00521	40.94	0.0000
T x A	1.29687	3	0.43229	0.80	0.4946
Error	49.44792	92	0.53748		
Spacing	14.43229	3	4.81076	10.81	0.0000
S x A	2.51562	9	0.27951	0.63	0.7727
Error	122.80208	276	0.44494		
T x S	2.18229	3	0.72743	1.50	0.2154
T x S x A	4.01562	9	0.44618	0.92	0.5093
Error	134.05208	276	0.48570		

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