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Component-levels theory of the effects of spacing of repetitions on recall and recognition

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Spacing repetitions generally facilitates memory for the repeated events. This article describes a theory of spacing effects that uses the same principles to account for both facilitatory and inhibitory effects of spacing in a number of memory paradigms. Increasing the spacing between repetitions is assumed to result in the storage of greater amounts of information of three types or levels: contextual, structural (associative), and descriptive. Contextual information is encoded automatically, while the encoding of the structural and descriptive information depends on control processes utilized. Remembering involves accessing the stored information using retrieval cues containing information on any level that matches the stored information. The ultimate effectiveness of the spacing is controlled by this matching between the retrieval cues and the stored information. Previous experiments demonstrating the operation of these principles on the structural and descriptive levels are reviewed. Three new experiments are reported that illustrate interactions between stored information and retrieval cues based on contextual information.

The effect of a repetition has always been of great importance to all theories of learning and memory. That performance improves with repetitions is one of the basic phenomena to be explained. Nonetheless, there is not an adequate explanation of when, how, or why repetitions are effective. No single-process theory, nor many multiprocess theories, can account for all, or even most, of the empirical findings. The goal of this article is to present a theoretical framework that integrates a number of different repetition-effect phenomena and that makes a variety of new predictions.

Specifically, the theory is designed to account for distributed practice and spacing effects found with verbal stimuli in a majority of verbal learning and memory paradigms. The distributed practice effect refers to enhanced memory performance on repeated items whose presentations are distributed (either through time or through time and other presentations), as opposed to performance on items whose presentations are massed or contiguous. In addition, in many situations the amount of distribution is positively correlated with performance. As the spacing, or lag, between the presentations increases, performance generally shows a concomitant, negatively accelerated improvement (Melton, 1970). Distributed practice effects, in one sense, have been difficult to explain because of their ubiquity across both tasks and information processing strategies (Underwood, 1969; Underwood, Kapelak, & Malmi, 1976). On the other hand, recent research (Glenberg, 1976, 1977) has pointed to ways in which the effect can be manipulated. Clearly, an explanation of distributed practice effects will have to deal with a variety of episodic memory situations, as well as the conditions that determine the effectiveness of a repetition, and hence, represents a good base from which to pursue repetition effects in general.

Many commonly accepted assumptions about the workings of memory are used in developing the theory; the relation between this theory and more general theories (e.g., Anderson & Bower, 1973; Craik & Lockhart, 1972; Kintsch, 1974) is intended to be obvious. Within these assumptions, distributed practice effects are explained using an amalgamation of various encoding variability approaches to spacing effects (e.g., Bower, 1972; Estes, 1955; Melton, 1970). Encoding variability positions propose that a stimulus undergoes changes in encoding from presentation to presentation, and that the extent of change is positively correlated with the spacing of the presentations. These changes in encoding add information to the episodic representation of the stimulus's presentations and underlies the improvement in performance.

As Hintzman (1974), Maskarinec and Thompson (1976), and others have noted, what it is that is assumed to be variably encoded is dependent on specific forumlations of encoding variability. It has been proposed that the variability resides in the semantic interpretation of events (Bower, 1972; Madigan, 1969), the context in which the events are encoded (Medin, Note 1), and the subjective organization in which the events are embedded (Melton, 1970). The present theory combined these notions by proposing that spacing effects can be due to variable encoding of any or all of three types of informational components.

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The theory adds to past formulations by specifying the conditions under which a given type of informational component will be variably encoded, and the conditions under which the variability will influence memory performance. In addition, the theory proposes that the different components share two abstract principles of operation that determine the effects of spacing, one concerning the processes of encoding and storage of information, and the other concerning the processes at retrieval. First, a repetition is potentially effective to the degree that the second presentation allows for the storage of information distinct from that stored at the first presentation. Second, the realization of this potential is controlled by the conditions at the time of the memory test, the retrieval environment.

The remainder of this paper is divided into four sections. The first section describes the theoretical framework in detail. The second section provides a selective review of the literature on spacing effects relevant to testing the theory. The third section consists of three new experiments, motivated by the theory, that expand the boundary conditions of the spacing effect, as well as providing additional tests of parts of the theory. The last section evaluates the theory in regard to other explanations of distributed practice effects and in regard to its own completeness.

COMPONENT-LEVELS THEORY

The name "component levels" is derived from two related aspects of the theory. The theory specifies three types of components that represent three types of information assumed to be important in most verbal learning and memory tasks. Additionally, these components may be roughly assigned to positions within a hierarchy (level) by considering their "generality": the number of different traces in which they are included.

Encoding and Storage Processes

Upon the presentation of a verbal stimulus, it is assumed that perceptual processes encode physical features of the stimulus. These features are then used to access the long-term permanent representation of the stimulus in semantic memory. This semantic memory representation is assumed to be composed of propositions giving the various features (e.g., its sound, spelling pattern, grammatical components, meaning, associations) of the item (Kintsch, 1974).

A multicomponent episodic trace is created to represent the occurrence of the stimulus in the experiment. The components of the episodic trace are also propositional, some of which are drawn from semantic memory. The specific components included in the trace are jointly determined by the stimulus being processed, the nature of the processing task, and the subject's strategies, as well as the context in which the stimulus is presented.

The components can be classified as one of three types, depending on the information encoded. Contextual components are automatically encoded upon the presentation of a to-be-remembered (TBR) item, and they represent the context in which the item is presented. Structural components encode the relationship discovered or imposed among sets of TBR items as a result of active processing. Descriptive components encode the specific item. The type of descriptive components encoded depends on the cognitive processes being used in the task (e.g., Craik & Lockhart, 1972).

Components on the three levels differ as to the probability that they are included in traces representing different items, that is, the generality of the components. A component that is included in many traces is said to be general. Since the same contextual components are included in all traces encoded in a specific context, they are, typically, general components. The same structural components are included only in traces subjects have successfully interassociated. Hence, these components are usually less general than the contextual components. Descriptive components may be unique to single traces. Processing demands of a specific task may, however, change the generality of a component. For example, if a great number of memorized items are associated to the same cue (e.g., a superordinate category), then the structural component representing the association will be very general.

Contextual components. These components represent the context in which the event is encoded and include such information as the characteristics of the physical environment, the time, and the learner's cognitive and affective stage (Anderson & Bower, 1974; Kintsch, 1974). The implicit assumption is that the events in a memory experiment do not occur in a cognitive vacuum, but are incorporated into the individual's stream of consciousness. For example, the trace representing the presentation of a word in a free recall list encodes not only the fact that a specific word was presented, but that it occurred in a given room, during an experiment, in a certain list, while performing a given cognitive operation.

Contextual information is given special status in two ways. First, it is assumed that components representing the context are encoded automatically with the perception of the individual TBR events. Second, as will be described below, it is assumed that contextual information can influence the encoding of other components included in the trace.

A repetition is potentially effective to the extent that different information is stored at the two presentations of a repeated event. The conditions under which new information is stored at the second presentation depend on the component. Since contextual information is automatically encoded, new contextual information is stored simply as a function of change in the context. Having a subject learn in two different rooms (environ-

mental contexts) is sufficient for the encoding of new environmental information (S. M. Smith, Glenberg, & Bjork, 1978). Other, less drastic changes in the context can result in the storage of new contextual components on the second presentation; for example, changes in the cognitive and affective states of the subject will also induce the storage of new components.

Different aspects of the context typically have different rates of change. For example, changes in the set of items being processed occur relatively quickly, and in effect, continuously. We can think of these as local contextual components; that is, these contextual features directly influence processing only in a constrained, local, temporal region. Some aspects of the context change more slowly over the course of an experimental session (e.g., the subject may be getting hungry over the course of the experiment). Finally, some aspects of the context, the global features, are typically unchanging or changing very slowly and are, hence, very general. Experiments 1-3 below demonstrate how these different aspects of the context can be experimentally separated, and how they affect performance.

The amount of change in the context, and hence the amount of change in the contextual components stored in the trace of a repeated item, is directly related to the time or lag between the presentations of the repeated item. This positive correlation between the number of different components stored in the trace and the repetition lag will be referred to as "differential storage."

Structural components. At the next level are the components representing the structure that the subject imposes on the individual events: which items are associated, grouped, categorized, or chunked together. These structural components are not stored automatically, but depend on the control processes engaged by the subject. For example, Bjork (1975), Glenberg and Bradley (in press), and others have demonstrated that when subjects engage in rote repetitive rehearsal, associations among TBR items are not formed. On the other hand, processes requiring the generation of relations do successfully structure the items.

The specific structural components included in the trace are determined by the local context. Cognitive aspects of the context—most importantly, the other items currently being processed—will affect the structure imposed on a set of items. That is, associations will be made only between items currently being processed (Anderson, 1972; Kintsch, 1974).

Whether or not new structural components are formed at the repetitions of stimuli depends on the context and on the encoding and storage processes being used by the subject. The learner must be engaging in some sort of structural analysis (e.g., relating TBR stimuli within a story, interactive imagery, etc.) if new structural components are to be added to the trace at the repetition. In addition, there must be a change in the structure assigned to the stimuli, a change induced by the context. For example, the stimulus may be repeated while the subject is processing a set of items different from those on previous presentations, allowing for the storage of new components in the trace of the repeated stimulus. Since changes in the context induce changes in the structural components, the structural components will themselves be characterized by differential storage. That is, if the learner is engaging in some sort of structural processing, then the number of different structural components stored in the trace will increase with the repetition lag.

Descriptive components. In the case of a TBR word, these components include information as to its orthography, articulation, meaning, and so on. Whereas the contextual and structural components are created anew at the presentation of stimuli (they encode the event as different from other presentations of the same stimulus), the descriptive components are copied from the semantic memory representation of the stimulus. The specific components copied into the episodic trace depend on the processing in which the subject is engaged and the context. Control processes affect the depth (Craik & Lockhart, 1972) to which the word is encoded, that is, the kinds of descriptive components included in the trace. Additionally, given that a physical stimulus has many different senses (Reder, Anderson, & Bjork, 1974), the local context affects the selection of components copied into the newly formed episodic trace. The process by which this selection takes place is assumed to be as follows: The pool of words currently being processed primes related propositions in memory. The components copied into the new episodic trace will include the primed propositions at the task-determined depth of analysis. Since these primed components are related to the traces being processed, they facilitate the formation of structural (relational) components and give memory its associative character.

Descriptive components are, in general, the most unique components included in the trace. It is possible, however, to manipulate the encoding of descriptive components or to design stimuli that all include the same components. For example, requiring subjects to process the pronunciation and sound of a set of rhyming stimuli would result in the inclusion of similar descriptive components in all the traces. These components would then be general.

Variability in the specific descriptive components that are encoded at the two presentations of a repeated stimulus is a function of both control processes and the local context. The subject may be induced to encode different aspects of the stimulus on its two occurrences by changing the orienting task between the occurrences. Or, more commonly, changes in the local context may effect a change in the primed components included in the trace (Bower, 1972).

So far, the theory has described the differential

storage of three classes of representational components that can occur upon the repetition of a stimulus in a memory task. The trace of a stimulus repeated after a substantial lag will include more contextual, structural, and descriptive components than the trace of an item repeated after a shorter lag. Nonetheless, the theory does not always predict a spacing effect as the result of differential storage. The amount of differential storage places an upper bound on the ultimate effectiveness of the repetition for later remembering. The extent and the direction of the correlation between differential storage and performance on a memory task is controlled by the retrieval environment.

Retrieval Processes

Remembering a specific stimulus requires retrieval of the episodic trace representing the occurrence of the stimulus in the experiment. Access to episodic traces is provided by retrieval cues. In component-levels theory, a retrieval cue consists of components similar to those included in the episodic traces. The components in the cue provide temporary, limited-capacity parallel activation of identical components included in the episodic traces (Lockhart, Craik, & Jacoby, 1976). The degree of activation of a component in an individual trace is inversely related to the number of traces in which the component is included (its generality). The degree to which the trace is activated is a monotonic function of the summed activation of its individual components. Therefore, (1) trace activation and retrieval are functions of the number of components shared by the cue and the trace, (2) trace activation decreases as the generality of the components in the trace or the cue increases, and (3) in general, trace activation increases with the number of components included in the trace.

This retrieval scheme follows the encoding specificity principle (Tulving, 1976) in that the cue is only effective to the extent it shares components with the episodic traces. In addition, a type of cue-overload hypothesis (Stein, 1978; Watkins & Watkins, 1975) is implicated, in that a cue loses its effectiveness as the number of traces with which it shares components increases.

The specific components included in the cue are dependent on the nature of the memory test, that is, the information available at the time of the test (Flexser & Tulving, 1978). Typically, this information includes instructions, the context at the test, and any explicit retrieval cues provided. Consider first a recognition test where the subject is provided with physical copies of the original stimuli and distractors and is asked to discriminate between the old and new stimuli. The subject begins the test by encoding a stimulus, thereby producing a cue consisting of components representing the context of the test and descriptive components of the stimulus. These components then activate identical components in the episodic traces.

If testing occurs after a short retention interval, then the local contextual components in the cue will activate traces containing components representing the same context that are included in traces of recent events. With longer retention intervals, the contextual components play a decreasing role in trace access for two reasons. First, after a long retention interval, the local contextual components in the cue will not correspond to the local contextual components in the episodic trace, so the components in the cue will not activate any components in the trace. Second, the global contextual components shared by the cue and the episodic trace are included in many traces (the components are general or overloaded), so that each trace will be only weakly activated.

The predominant source of trace activation on a recognition test will be the descriptive components. The cue will contain a plethora of unique descriptive components. Generally, if the cue is physically identical to a previously presented word, the trace of the cued word will be strongly activated and result in recognition. On the other hand, if the encoding of the item at input was impoverished (i.e., contained few components due to inattention, fast presentation, shallow processing, etc.) or the encoding of descriptive components at the test is radically different from the encoding at input (e.g., two different meanings of a homograph), the cue will not retrieve the trace.

Retrieval in other situations is controlled by the same processes but, at times, with components at different levels. Consider retrieval in free recall. Shortly after list input, the local contextual components on the test will activate the traces including identical components, those processed near the end of the list. Thus a recency effect is produced in immediate free recall, but not in a delayed free recall where the local contextual components in the cue do not correspond to the components in the traces (Tulving, 1968). The global contextual components will heighten the activation of all TBR items. This component can be used as a gate to eliminate extraexperimental confusions. Because these components are included in all TBR traces, however, the cue is relatively ineffective.

Traces recovered with the contextual cue can themselves become sources of retrieval cues. If structural components (representing categorical or subjective organizations) are included in the recovered traces, then these components can also serve as effective cues. Since only a few traces are typically included in a subjective structure (e.g., Mandler, 1972), these traces will all be highly activated by shared structural components. Of course, the effectiveness of recovered items as a source of structural components will depend on the subject's previous processing, that is, whether or not the items were structured during input. Finally, the set of descriptive components included in a recovered trace can be used to activate traces having identical descriptive components. Additionally, the descriptive components

are used to retrieve the lexical representation of the item in order to generate an overt response.

When components from multiple levels are included in the cue, trace access is predominately controlled by the most specific components, since the more general components will tend to be overloaded. Nonetheless, once a trace has been accessed, general components in the trace may be used to control performance (e.g., contextual components may be used for judgments of presentation frequency).

Distributed Practice Effects

Increasing the repetition lag will, typically, lead to differential storage of the components on one or more levels, and differential storage will, in general, facilitate remembering. The more different components included in the trace, the more likely that the trace will share components with the cue and, hence, be activated and retrieved. The ubiquity of the lag effect is explained by the built-in redundancy of most experiments; differential storage may be eliminated on some levels, but the remaining levels can still produce a distributed practice effect.

The facilitation in remembering due to increasing the repetition lag may not, however, always be found. Two situations arise in which differential storage does not manifest itself in performance as a monotonically increasing lag effect. Both situations result from trace accessibility being conditional upon sharing components with cues used at the time of remembering. First, differential storage may occur at one level and retrieval prompted with cues containing less general components. Since access to the trace is controlled by the most unique components in the trace, the differential storage will not greatly influence performance. This prediction is tested in Experiment 1. During input, differential storage of contextual components is left uncontrolled. Differential storage is eliminated, however, in the structural and descriptive components. Free recall, using the putative contextual cue, results in a distributed practice effect. When descriptive components are included in the cue (cued recall), the distributed practice effect is eliminated.

The second situation is more complicated. On any level, manipulating the relationship between the cue and the information stored in the trace may produce performance, as a function of the repetition lag, that is monotonically decreasing, inverted U shaped, or monotonically increasing. Figure 1 illustrates these predictions considering only one level.[1] On the left are times during which an event may be presented and repeated. Corresponding to each time are the components that are encoded at that time. The gradual change in the components available for encoding is due to changes in the context, although contextual changes in an experiment are certainly not as orderly as shown in the figure.

TIME	COMPONENTS
⋮	⋮
t1	ghij
t2	hijk
t3	ijkl
t4	jklm
t5	klmn
t6	lmno
t7	mnop
t8	nopq
⋮	⋮

		REPETITION STRUCTURE			
LAG		0	1	2	6
PRESENTATION TIMES		t7+t8	t6+t8	t5+t8	t1+t8
COMPONENTS IN TRACE		mnopq	lmnopq	klmnopq	ghijnopq
NUMBER OF ACTIVATED COMPONENTS	CUE 1 (mnop)	4	4	4	3
	CUE 2 (lnqs)	2	3	3	2
	CUE 3 (random)	4·5/n	4·6/n	4·7/n	4·8/n

Figure 1. On the left are times at which an event may be repeated and the components (on one level) stored at the presentations. On the right are components included in traces formed after repetitions at four lags, the structure of three retrieval cues, and the number of components in the traces activated by the cues.

Consider an event presented at times t_5 and t_8. The repetition results in a trace containing components k-q, as indicated on the right. Also shown are the components in traces corresponding to events repeated at t_8 after four different lags. The increase in the number of components included in the traces illustrates differential storage as a function of repetition lag.

The figure also details trace activation provided by three cues. For illustrative purposes, these cues consist of components on only one level. These cues differ in their bias toward including components stored at t_8. Cue bias is defined as the tendency to include in the cue components stored at one presentation of the TBR item, and to exclude from the cue components stored at other presentations of the TBR item. The components in a strongly biased cue are sampled from a probability distribution, having small variability, centered on the components encoded at the presentation toward which the cue is biased. As the bias decreases, the probability distribution becomes more variable. An unbiased cue contains components drawn from a rectangular probability distribution, so that components available at all presentations are equally likely to be included in the cue.

Cue bias can be controlled through direct experimental manipulation (Glenberg, 1977; Experiment 3 of this article), or indirectly by the retention interval. When the second presentation of a repeated event is followed by a short retention interval, the local context at the test will be similar to the local context at the second presentation. The contextual components included in the retrieval cue will, therefore, be biased toward those encoded at the second presentation. In addition, on a recognition test, to the extent that the local context influences the encoding of descriptive components, the cue will contain descriptive components biased toward those encoded at the second presentation (Glenberg, 1976).

The first cue in Figure 1 is an example of one that is highly biased toward the components encoded at the second presentation. The number of components shared

by the cue and the trace is relatively large, leading to much activation and relatively high performance. Note, however, that the amount of activation is a decreasing function of the repetition lag. A "reverse" distributed practice effect is generated with this cue.

The second cue is also an example of bias toward the components presented at the second presentation, but the bias is not as great as in the first cue. Trace activation, based on the second cue, is a nonmonotonic, inverted U-shaped function of the repetition lag.

The third cue is not biased toward either presentation. The numbers entered into the table are the expected number of activated components assuming that four different components (out of a possible n) are randomly chosen for inclusion in the cue. Only in this last case is performance a monotonic function of the repetition lag. In most experiments the retrieval cues are unbiased, resulting in the third cue type and the common, monotonically increasing lag effect (see Glenberg, 1976, for a mathematical derivation of these three types of spacing functions).

Nonmonotonic spacing functions have been well established in the paired associate paradigm (Atkinson & Shiffrin, 1968; Glenberg, 1976; Peterson, Wampler, Kirkpatrick, & Saltzman, 1963; Young, 1971). Component-levels theory provides a description of the conditions that control the shape of the spacing function in this paradigm as well as in others.

TESTS OF THE THEORY

The theory is in need of evidence supporting the notion of different levels of components and cues, and that spacing effects may occur due to differential storage on any or all of the levels. Although component-levels theory makes use of many previous theories, not all of the tests of these theories can serve as tests of component-levels theory. The major problem is that simply increasing the lag between presentations of a repeated item may induce differential storage on a number of different levels. Therefore, demonstrating a lag effect does not isolate a level. Likewise, eliminating differential storage on one level does not necessarily imply the absence of a lag effect if differential storage is not eliminated from other levels relevant to the retrieval cues.

Two approaches may be used to isolate spacing effects on a single level. The first is to simply eliminate the effects of differential storage on all but the target level. This can be accomplished either by insuring that the number of new components on the nonrelevant levels added at the second presentation is small and does not vary across lag conditions (encoding constancy), or that the number of new components added at the second presentation is always very great and does not vary across lag conditions (maximum encoding variability). Unfortunately, encoding constancy may be unattainable. The local context is always changing, so that differential storage of these components will occur. The changing local context may also influence the encoding of descriptive and structural components even when the same semantically biasing contexts are used at each presentation.

A second approach to isolating spacing effects to a given level is to eliminate the influence of components on general levels by presenting subjects retrieval cues of less general components. As discussed before, trace access is predominately controlled by the most specific components in the cue.

Once a single level has been isolated, tests of component-levels theory's explanation of the lag effect may be made. The two major types of tests involve manipulations at either input or retrieval. At the time of storage, the experimenter may enhance the lag effect by promoting differential storage or eliminate the effect by eliminating differential storage either through encoding constancy or maximum encoding variability. At the time of retrieval, the relationship of the cue to stored information may be manipulated. As described above (see Figure 1), this manipulation can change the shape of the lag function from monotonically increasing, to inverted U shaped, to monotonically decreasing.

Descriptive Components

In general, increasing the lag between presentations will increase the number of descriptive components included in the trace and lead to an increase in recognition performance. A number of investigators (Earhard & Landry, 1976; Glenberg, 1976; Hintzman, 1969, using recognition time as the dependent variable; Kintsch, 1966; Wichawut, Note 2) have observed this correlation. In addition, Earhard and Landry, as well as Wichawut, found that inducing maximum encoding variability of descriptive components tended to eliminate the lag effect. As predicted by the theory, recognition performance was high and constant across spacing conditions. Both articles also reported, however, that recognition performance increased with lag in those conditions where encoding constancy was attempted. This finding may reflect continuous changes in the local context that prevent encoding constancy.

The predictions illustrated in Figure 1 were tested at the level of descriptive components by Glenberg (1976). A continuous recognition memory paradigm was used. On each occurrence of an item, the subject was to indicate whether the item was previously presented (old) or new. The lag between the first two presentations was factorially combined with the retention interval between the second and third presentations. After a short retention interval, the local context at the third presentation will be similar to the context at the second presentation. Consequently, both the contextual and descriptive components in the cue will be biased as in Cue Types 1 and 2 in Figure 1. After a long retention

interval, the context at the third presentation will be asymptotically related to the context at the first and second presentations. The components included in the cue will be unbiased, as in Cue Type 3 in Figure 1. As predicted, the probability of correctly recognizing an old item was an inverted U-shaped function of lag when tested after a short retention interval, and a monotonically increasing function of lag when tested after a long retention interval.

Distributed practice effects in the paired associate paradigm may be ascribed to the descriptive components or structural components. The ambiguity arises when considering what a subject learns when a paired associate is studied. If learning is conceptualized as "hooking-up" a response to a stimulus by creating a structural component, then differential storage of structural components may occur. On the other hand, Greeno (1970) has had much success explaining paired associate phenomena with a cognitive theory of learning. The first stage of learning is conceptualized as the storage of a trace encoding a unitary relation between the stimulus and the response. The second stage involves learning to encode the stimulus so that it retrieves the relation. Distributed practice effects may, therefore, be due to differential storage of descriptive (stimulus) components during the second stage of learning. Component-levels theory remains neutral on this point. For convenience, Greeno's (1970) interpretation of paired associate learning will be accepted, and distributed practice effects will be analyzed at the level of descriptive components. Increasing the lag between presentations of the pair, which is correlated with changes in the local context, offers the opportunity for differential storage of (stimulus) descriptive components in the trace. On the test, the subject encodes the stimulus member of the pair as a cue to the relational trace. Increasing the repetition lag should, in general, increase the number of different components in the trace, and therefore increase the number of components shared with the cue. Once the trace has been retrieved, the response must be decoded and output. Note that the processes that produce distributed practice effects in the paired associate paradigm are essentially the same as those in the recognition memory paradigms.

In agreement with the assumption that distributed practice effects in the paired associate and recognition memory paradigms are predominantly based on descriptive components and cues, lag effects involving paired associates are essentially the same as for recognition memory experiments and follow similar time courses. First, increasing the lag between presentations of paired associates typically produces increases in cued recall. Second, the shape of the lag effect can be manipulated by varying the retention interval between the second presentation and the test. At very short retention intervals, the lag function is decreasing (Peterson, Hillner, & Saltzman, 1962). With slightly longer retention intervals, the lag function is an inverted U-shaped function (Peterson et al., 1963). Finally, with long retention intervals, the function is monotonically increasing (Glenberg, 1976).

Structural Components

When an item on a free recall list is repeated, it may become associated with different items on its two presentations. This differential storage of structural components increases with changes in the context (especially the other words being processed), and hence with the lag. Thus, as the repetition lag increases, the number of different associations involving the repeated word increases, and the probability of recall increases. This prediction of an increase in free recall with the repetition lag has been confirmed in many investigations (Glenberg, 1977; Madigan, 1969; Melton, 1970). Of course, some of the effect of lag seen in free recall may be due to differential storage of contextual components and descriptive components, in addition to the structural components.

Some attempts have been made to isolate the effects of structural components in free recall. Glenberg (1977) compared recall of subjects who were encouraged to form associations among list items and subjects who were prevented from doing so. In the former condition, the lag effect is influenced by differential storage of structural, descriptive, and contextual components. In the latter condition, the spacing effect should be attenuated due to the elimination of differential storage of structural components. As predicted, the subjects encouraged to form associations produced a strong lag effect in recall. The other group showed an increase in recall from Lag 2 to Lag 5, and then no improvement (out to Lag 17). Similar findings were reported by D'Agostino and DeRemer (1973, Experiment 1, free recall, and Experiment 2, image-same condition). Apparently, eliminating differential storage of structural components reduces the spacing effect from moderate to long lags, but does not change the effect at shorter lags.

DeRemer and D'Agostino (1974) limited the processing time on the second presentation of repeated events. This manipulation should also reduce differential storage of structural components. Again, spacing effects were eliminated from moderate to long lags. In general, these results may be interpreted as showing that the spacing effect in free recall is predominantly due to differential storage of structural components. Differential storage of contextual and descriptive components seems to have a small effect at the short lags, but not at moderate or long lags.

Nonmonotonic lag effects based on structural components may be produced by manipulating the relationship between the structural components in the retrieval cues and the stored information in a manner analogous to that using descriptive components.

Glenberg (1977, Experiments 1 and 2) repeated words in a free recall list at lags of 2, 5, and 17. Each repeated word was assigned two once-presented words that could be used as recall cues. These possible cues were presented between the two presentations of the repeated word, one cue adjacent to each presentation. When recall was cued, each repeated word was cued with one of the two possible cue words.

It was assumed that while studying the list, the subjects imposed a structure on the individual words that was at least in part determined by contiguity of the words (Wallace, 1969). Therefore, the structures including repeated words will tend to include the possible cue words. As the lag between the presentations of repeated words increases, the number of different structural components included in the trace of the repeated word will increase; that is, there will be differential storage. When recall is cued with unbiased contextual cues (free recall), the differential storage of contextual and structural cues will produce the monotonic, increasing lag function. When recall is cued, the cue words provide a source of structural components biased toward one presentation—the presentation adjacent to the once-presented cue word—and the spacing function should be nonmonotonic. As predicted, free recall resulted in the monotonic lag effect, while cued recall, using the biased cue word, resulted in an inverted U-shaped lag function.

Contextual Components

Indirect evidence for the operation of contextual components in producing a spacing effect is provided by experiments reported by Maskarinec and Thompson (1976, Experiment 2) and Shaughnessy (1976). Both used an incidental learning procedure with orienting tasks that forced subjects to process individual words and provided no incentive to form associations between the words. According to component-levels theory, this manipulation should eliminate differential storage of structural components. (Shaughnessy discusses a mechanism whereby associations between words may be formed as a by-product of his orienting task, but his analysis does not apply to the Maskarinec and Thompson task.) Within the list some items were given massed presentations (MPs) and other items were given distributed presentations (DPs). Half of the subjects used the same orienting task on all presentations, while half of the subjects used a different task at each presentation. After performing the orienting task, the subjects were unexpectedly asked for free recall.

Maskarinec and Thompson (1976) reasoned that the traces formed in the different-task condition encode many descriptive components regardless of the repetition lag. That is, in order to perform the different-condition orienting tasks, the subject must encode the same descriptive components when the presentations are massed as when they are distributed. Therefore, Maskarinec and Thompson predicted (from a simple encoding variability point of view) that the massed-distributed difference would be eliminated in the different-task condition. Shaughnessy (1976) derived a similar prediction from a different theoretical perspective.

If performance is tested with a recognition test, component-levels theory would also predict no difference between MP and DP. That is, the efficacy of the descriptive components used as retrieval cues in recognition is equated across presentation conditions by the orienting tasks. The theory makes a different prediction, however, for free recall. Presumably, the orienting tasks eliminated storage of structural components, but the tasks should not have eliminated differential storage of automatically encoded contextual components. Free recall, in which contextual components are the only available retrieval cues, should therefore result in a spacing effect. As predicted, the recall after DP was superior to the recall after MP in both the Maskarinec and Thompson (1976) and the Shaughnessy (1976) experiments.

The memory trace of an event also includes contextual components representing the physical environment in which the event is perceived (Abernethy, 1940; S. Smith & Guthrie, 1924). A type of differential storage of these environmental context components is illustrated in an experiment by S. M. Smith et al. (1978). The subjects were presented for study the same list of words in two sessions separated by 3 h. Half of the subjects studied the list in the same room in both sessions, the other subjects studied the list in two different rooms. Recall was attempted in a third session, 3 h later, in a room new to all of the subjects. Those subjects who studied the list in two different rooms recalled an average of 40% more words than the subjects who studied the list of words twice in the same context. This finding can be explained by assuming that the components in the traces that represent the global environmental context underwent little change for the words studied twice in the same context. For the subjects that studied in two rooms, however, the traces contained components representing both environments. At testing, in a new room, the contextual cue did not include many components stored at either the first or the second presentation. Nonetheless, the total number of components shared by the cue and the traces was greater when the words were studied in two contexts than in one context, producing the enhanced recall.

The environmental context cue should be open to the same manipulations as the other cues. For instance, as the difference between the two study contexts increases, recall should show a concomitant increase when testing is in a context randomly related to the input contexts (e.g., Cue 3 in Figure 1). When recall is tested in a context that is similar to one of the input contexts (e.g., Cue 1 or 2 in Figure 1), recall should

not increase monotonically with the difference between the contexts. The latter prediction is tested and confirmed in Experiment 3.

In summary, this review has shown that component-levels theory can account for many of the standard findings in experiments on the spacing of repetitions, as well as integrating results across paradigms. Also illustrated are various methods that can be used to test the theory. Unfortunately, most of the experiments reviewed were not specifically designed to test the theory, and therefore, some of the analyses are post hoc. The three experiments to be reported here were designed to provide new tests of the theory's explanation of distributed practice effects, especially in regard to contextual components. Experiment 1 provides evidence for distributed practice effects due to descriptive components and local contextual components. The results of the experiment also provide support for the assumption that cuing with unique components eliminates effects due to differential storage of general components. Experiment 2 examines the interaction between structural components and contextual components, while providing direct evidence for cue bias. In addition, the experiment provides a plausible account for the very long lag effects observed in free recall. Experiment 3 does not include distributed practice as an independent variable, but involves a more direct manipulation of differential storage of components representing the environmental context. The experiment replicates and extends S. M. Smith et al. (1978). The results demonstrate that differential storage of the environmental contextual components can lead to improved memory performance, but only in conjunction with retrieval cues that take advantage of this differential storage.

EXPERIMENT 1

This experiment was designed to examine interactions between descriptive components and local contextual components. The subjects in the experiment were asked to study a list of paired associates. The list was composed of normatively related pairs (e.g., blade-knife). All pairs (except for primacy and recency buffers) were repeated within the list. Half of the pairs were given MP, and the others were given DP. At the second presentation, half of the pairs were repeated exactly (constant condition), while for the remaining pairs, the right-hand member was the same, but the left-hand member was changed, for example, spoon-knife (varied condition). After the input stage of the experiment, half of the subjects were given a free recall test, and the other half of the subjects were provided with the left-hand members of the pairs as cues for the right-hand members.

Normatively related word pairs were chosen to insure that (1) the subjects would study the pairs as pairs rather than as individual words, (2) the subjects would have no trouble finding a relationship between the two words and storing that relationship, and (3) the two pairs in the varied condition would be viewed as related pairs (or a triple), rather than two unrelated pairs. If these assumptions are met, then we can represent the important components of the memory trace, after the two presentations, as follows:

MP-constant	DS + C	MP-varied	$D_1D_2S + C$
DP-constant	DD′S + CC′	DP-varied	$D_1D_2S + CC'$

The "D" represents descriptive components, the "S" represents the structural relation between the stimulus and response, and the "C" represents the contextual components. For the traces presented in the varied conditions, the subscripts indicate that the stimulus descriptive components come from two different stimuli. For the DP traces the primes indicate variability in components (descriptive and contextual) due to local contextual changes. As can be seen, there is differential storage of contextual components that is highly correlated with the MP-DP variable, but relatively independent of the varied-constant variable.

Next, consider the descriptive components. Since two stimulus terms are always presented in the varied conditions, there are more different stimulus descriptive components stored than in the constant conditions. Within the varied conditions there is no difference in the descriptive components between the MP- and DP-varied pairs. Within the constant conditions the MP-DP variable does produce differential storage of descriptive components. Local contextual changes increase the number of different descriptive components in the DP-constant pairs relative to the MP-constant pairs.

Component-levels theory predicts a different interaction between the varied-constant and MP-DP variables on the cued and free recall tests. On the cued recall test the subject is given a stimulus to use as a cue to retrieve the pair. Since descriptive components are available, the contextual components will not greatly influence performance. In the constant conditions, the encoded stimulus (the retrieval cue) is more likely to share descriptive components with pairs in the DP condition than in the MP condition. Therefore, recall of the DP pairs should be superior to recall of the MP pairs. In the varied conditions the subjects are given both stimuli, one at a time, with which to retrieve the response. The likelihood that these cues share components with the traces is equivalent for the MP and DP pairs in the varied conditions, but greater than for the pairs in the constant conditions. Therefore, in the varied conditions cued recall is predicted to be independent of the MP-DP variable and greater than in the constant condition.

In free recall the retrieval cue consists of the context

at the time of the test. This cue is more likely to share components with the pairs given DP than MP, regardless of the varied-constant variable. DP items should be recalled better than MP items in both varied and constant conditions. In addition, the pairs given varied presentations will be recalled better than the pairs given the constant presentations. If the subject fails to store a relation between the stimulus and response of a pair given varied presentation on the first presentation, the second presentation offers an essentially independent opportunity for learning. Unless there is a sufficient change in context (and hence a chance to encode a new relationship between the stimulus and response), this will not occur for the pairs given the constant repetition.

Method

Subjects. A total of 64 subjects was drawn from introductory psychology courses taught at the University of Wisconsin–Madison. Participation in experiments is one way of fulfilling a course requirement. They were randomly assigned to the free and cued recall conditions.

Materials and Design. Sixty-one triples of words were drawn from various association norms. What was to become the response term in the present experiment was the stimulus word in the norms. One of the other words was a high-frequency response, the other was a low-frequency response. Thirteen of the triples were used for practice and buffer pairs; the other 48 triples were used in the main experimental conditions.

The basic list structure consisted of five once-presented primacy buffer pairs, followed by the presentation of 24 pairs, each of which was repeated, and ending with five once-presented recency buffer pairs. Half of the repeated pairs were in the constant condition; that is, both members of the pair were repeated. For the other pairs, the stimulus term was changed while the response term remained the same on the second presentation (varied condition). Orthogonal to this manipulation, half of the pairs were given MP and half of the pairs were given DP. The distribution lag varied from two to six intervening pairs. The presentations (excluding the buffers) were arranged in blocks of eight. Within a block, one pair of each of the four types was presented twice.

Counterbalancing over subjects insured that (1) each pair was used equally often in each of the four main conditions, (2) in the varied condition each of the two stimuli associated with a given response was used equally often on the first and second presentations of the pair, and (3) in the constant condition each stimulus was used equally often.

The subjects who received cued recall were given a booklet containing 54 pages. On each page was a single stimulus term and a blank space for the response paired with that stimulus. The first six stimuli consisted of three stimuli from each of the buffers. The remaining 48 pages consisted of two cued recall tests for each response term. One of the tests was in the first 24 pages; the other was in the last 24 pages. For those pairs given varied presentations, both of the presented stimuli were used as cues once. The order of the presentation of sets of 24 recall trials was counterbalanced over subjects.

Procedure. The subjects were run individually. The pairs were projected, one at a time, using a Kodak Carousel projector. The total study time for each pair (including the time needed to change slides) was 4 sec. The subjects were instructed that they were to see a long list of pairs of words. They were to try to memorize the pairs as pairs, not as single words. In addition, they were told that their memories for the pairings would be tested, although they were not given any specific details of the testing procedure. The subjects viewed three practice pairs before beginning the main list.

The subjects given free recall were asked to write down as many of the words as they could remember, either singly or in pairs. The subjects given the cued recall tests were handed the booklet and instructed to try to write down a response word next to each stimulus word. They were encouraged to write a word on every line, but they were not forced to guess. Recall was self-paced for both groups.

Results and Discussion

The probability of a Type I error is set at .05 for all statistical analyses.

The data of main interest are presented in Figure 2. The interaction between type of recall, varied-constant, and distribution was statistically significant. To facilitate the interpretation of the results, two identical analyses of variance were performed, one for cued recall and one for free recall. Each analysis was an 8 by 2 by 2 (counterbalancing by varied-constant by distribution) analysis, with the last two factors being within subjects. For cued recall, the effects of varied-constant repetition [$F(1,24) = 10.69$, $MSe = 1.35$], distribution [$F(1,24) = 5.81$, $MSe = .84$], and their interaction [$F(1,24) = 5.44$, $MSe = .63$] were all significant. For free recall, the effect of varied-constant [$F(1,24) = 6.29$, $MSe = 1.61$] and distribution [$F(1,24) = 5.67$, $MSe = 1.41$] were significant. The F ratio for the interaction was only .18.

Clearly, all of the predictions of component-levels theory were upheld. For cued recall, the descriptive components in the cue appear to provide access to the traces. In the constant conditions, this cue along with differential storage of descriptive components produces the MP-DP difference. In the varied conditions, maximum encoding variability of descriptive components is induced for both MP and DP pairs. Therefore, cued recall is high and unaffected by the MP-DP variable. In free recall, retrieval is controlled by the contextual

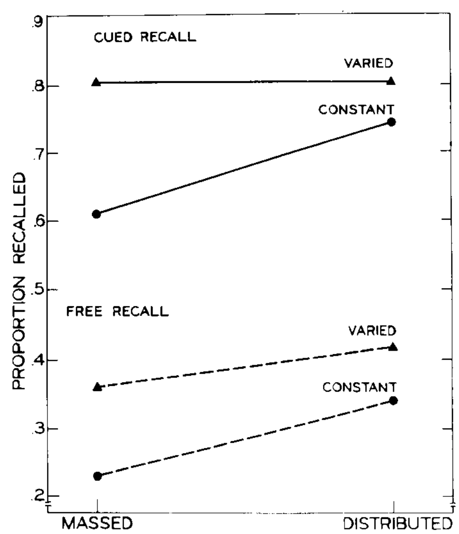

Figure 2. Mean cued and free recall of response terms as a function of type of repetitions and the spacing between the repetitions.

components available on the test. Since differential storage of contextual components is independent of the constant-varied manipulation, the MP-DP effect is found in both conditions.

In the introduction, predictions were made assuming that the effect of differential storage of general components could be eliminated by providing retrieval cues composed of unique components on a different level. This assumption, if valid, provides a convenient method for testing the theory. The differences between the results on the cued and free recall tests provide some validation for the assumption. Differential storage of general contextual components underlies the MP-DP effect in free recall where the retrieval cue is composed predominately of unique descriptive components, differential storage of contextual components does not affect recall.

Predictions similar to those made above have been disconfirmed in other studies. Shaughnessy, Zimmerman, and Underwood (1974), for example, reported an experiment similar in design to Experiment 1, but with quite different results. There are a number of differences between the experiments, of which the most important for component-levels theory is that unrelated words were used to construct the pairs. This difference may have led the subjects in the varied conditions to store completely different traces for each presentation, nullifying many of the predictions.

EXPERIMENT 2

This experiment was designed to examine the effects of differential storage of contextual components and their interaction with structural components. As discussed before, the context is composed of some relatively quickly changing aspects (e.g., the words currently being processed) and some components that change less quickly (e.g., the current list being processed, the subject's mood). The major concern of Experiment 2 is with the latter, more global components of the context. The basic idea is to isolate the effect of differential storage of global contextual components by insuring constant (with respect to lag) encoding variability of descriptive components and structural components. On the recall test the relationship between the contextual cue and the components in the trace is manipulated as in Figure 1 to produce monotonically increasing and decreasing lag functions.

The design involved the presentation of 10 or 11 lists of words for free recall. Within each list, words were repeated at lags of 0, 2, 8, and 20. Some of the lists were recalled immediately after their presentations, others were not recalled until a final recall test. The lists not recalled immediately will be referred to as the critical lists. Embedded within the critical lists were repeated words whose second presentations were in List 10. The serial position of the critical lists is, therefore, inversely related to the between-lists repetition lag. The words repeated between the lists all have maximum or close to maximum encoding variability of descriptive and structural information (based on changes in the local context), regardless of the between-lists lag. Only the global contextual components can be affected by differential storage.

After presentation of List 10 (which contained the repetitions of the words repeated between lists), half of the subjects were given an immediate final free recall for all of the lists. The global context during this test will be similar to the global context during the presentation of the recent lists. The contextual components in the cue, therefore, will share many components with the traces formed during presentations in recent lists (short between-lists lags) and fewer components with traces whose first presentations were in the earlier lists (long between-lists lags). The contextual cue is biased like Cue 1 or 2 in Figure 1, hence recall of the words repeated between lists is predicted to be monotonically decreasing or an inverted U-shaped function of the between-lists lag. Based on the same reasoning, the theory predicts a general list-recency effect. The contextual components in the cue are biased toward (include components from) the last few lists. Items presented only on the last lists should be recalled better than those presented only in the first lists (Bjork & Whitten, 1974).

For the other subjects, List 10 was not immediately recalled, but List 11 was presented and it was recalled. These subjects received a delayed final recall of all the lists after an interval of 1.5 to 2.5 h. At this time the bias in the global contextual components of the cue is greatly reduced. As with Cue 3 in Figure 1, recall of the words repeated between lists is predicted to be a direct function of differential storage of the global contextual components and to increase monotonically with the between-lists lag. Additionally, since the cue is unbiased, the list-recency effect should be eliminated. Items presented only on the last lists should be recalled about as well as items presented only on the first lists.

Method

Materials and Design. Four different list structures were used. One of the structures was used for List 10, which contained the second presentations of the words repeated between lists, one was used to construct the four critical lists, and the other two structures were used to construct the remaining six lists. All of the structures contained 54 serial positions, of which the first 5 and last 6 were filled with once-presented words to make up the primacy and recency buffers, respectively. Except for the List 10 structure, within the body of the structures were places for four exemplars of words repeated at each lag of 0, 2, 8, and 20. In addition, there were spaces for 11 words presented once in the list. The differences between the list structures were in the assignment of the various conditions to serial positions. In each of the four critical lists, 4 of the 11 once-presented words were given a second presentation in List 10.

Within the body of List 10 were two exemplars of words repeated within the list at each of Lags 0, 2, 8, and 20, 11 words

given a single presentation, and the second presentations of the 16 words that had received their first presentations on the four critical lists.

Lists presented in Positions 1, 2, 4, 5, and 7 were recalled immediately after their presentations. The critical lists were presented in Positions 3, 6, 8, and 9. The between-lists repetition lags were, therefore, 0, 1, 3, and 6, corresponding to words whose first presentations were in Lists 9, 8, 6, and 3, respectively.

Four different list orders (assignments of specific lists to list serial positions) were used. Across the different list orders, each of the critical lists occurred equally often in Serial Positions 3, 6, 8, and 9. This procedure served to counterbalance both specific words to serial positions and the words repeated between lists to between-lists lags. The serial positions of the five noncritical lists were randomized in each list order under the constraint that a given list could not occur more than once in a given serial position. Within each list order, the words within a list were counterbalanced to insure that a repeated word appeared equally often in each of the between- and within-lists lag conditions. List 10 (and for the subjects who received the delayed final recall, List 11) was the same for all subjects.

In all, 418 common, single-syllable, four- and five-letter nouns were used as TBR words. The words were assigned to the lists and conditions randomly except for the constraint that each list have approximately the same proportion of four- and five-letter words.

Procedure. All subjects were run individually. They were instructed that the experiment was designed to measure the effect of recalling one list upon the recall of the next list. Consequently, they would have to try to memorize each list of words, although only some would be recalled and the rest would be followed by arithmetic problems. The subjects were also informed that some words would be repeated. They were not informed of the total number of lists, which lists would be recalled immediately, or that a final recall would be requested.

The words were projected one at a time with a Kodak Carousel slide projector controlled by external timing apparatus. The total study time per word, including the time between slides, was 3 sec. After the presentation of each list, the subjects were given one of two instructions, either to recall the words or to do arithmetic problems. When instructed to recall, they were given 1 min to free recall the words. After presentation of the critical lists, the subjects were instructed to do arithmetic problems. Simple multiplication problems were presented, one every 2 sec, for a total of 1 min. The subjects were required to write down the answers to the problems.

The subjects receiving the immediate final recall received an additional instruction immediately following the presentation of List 10. They were told at that time to try to recall all of the words from all of the lists. In addition, they were told that they would receive a bonus of 1 cent for every word they could recall.

The subjects receiving the delayed final recall performed arithmetic following List 10. They then studied and recalled List 11. These subjects returned to the laboratory between 1.5 and 2.5 h later. In the second session, these subjects were asked to recall all of the words from all of the lists. They were also paid the bonus of 1 cent for each word recalled.

Subjects. A total of 120 volunteers was drawn from the University of Wisconsin introductory psychology classes. Participation in experiments is one way of fulfilling a course requirement. The first 60 subjects were assigned to the immediate final recall condition. The next 60 subjects were assigned to the delayed final recall condition. The two halves of the experiment were separated by the semester break and, therefore, the two sets of subjects were drawn from different classes. Although the subjects were sampled at different times of the year, the two halves of the experiment were conducted during the same relative parts of the academic semesters.

Results and Discussion

Three different analyses of recall of the repeated words were conducted. The dependent variables were (1) immediate recall from the noncritical lists in Positions 1, 2, 4, 5, and 7, (2) final recall from the previously unrecalled (critical) lists in Positions 3, 6, 8, and 9, and (3) final recall of the words repeated between lists. Each analysis of variance, except for the last, included the factors delay of final recall, list order, counterbalancing within a list, list serial position, and within-lists lag. The last two factors were within-subjects manipulations. The analysis of the recall of the words repeated between lists did not include the within-lists lag factor.

Consider first the immediate recall from the noncritical lists. The important means from this analysis are presented in the upper panel of Figure 3. The effect of within-lists lags was statistically significant [$F(3,240) = 46.65$, $MSe = .62$]. There was also a main effect for list serial position [$F(4,320) = 3.01$, $MSe = .78$]; recall declined from about 30% on the first list to between 25% and 27% on the others. There was no main effect for delay of final recall, although this factor did interact with the within-lists lag [$F(2,240) = 3.59$, $MSe = .62$]. For unknown reasons the subjects in the delayed final recall condition did not show an increase in recall from Lag 8 to Lag 20 on the immediate recall tests. Other significant effects include a main effect for within-lists counterbalancing and higher order interactions involving the counterbalancing variables. These interactions appear to be due to unsystematic variations in recall and do not affect the main conclusions.

The final recall of the words repeated within the critical lists offers a number of tests of component-levels theory. Once the contextual cue provides access to a trace, the structural components in the trace may

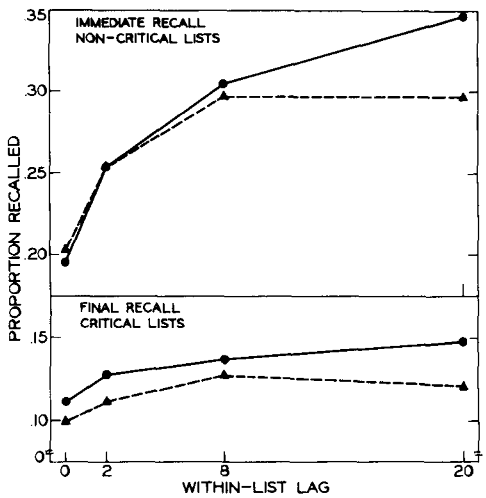

Figure 3. Mean recall of words repeated within the lists. Solid lines represent recall from subjects who received the immediate final recall. Dotted lines represent recall from subjects who received the delayed final recall.

be used as an associative cue to other traces. Since structural components within each list have undergone differential storage, they produce a within-lists lag effect. This effect will be independent of the list serial position since the stored relationships represented by the structural cues are not influenced by any global context bias at the test. For the final recall of words repeated in the critical lists, the main effect of within-lists lag was significant (see Figure 3) [$F(3,240) = 2.88$, $MSe = .41$]. Within-lists lag did not interact with either list serial position or delay of final recall (both $Fs < 1$).

Final recall of words repeated within the critical lists, averaged over within-lists lag, is presented in Table 1. The list-recency effect on the immediate final recall illustrates the effect of biased global contextual components in the cue. The flat list serial position function in the delayed final recall indicates an unbiased global contextual cue. The interaction was significant [$F(3,240) = 4.21$, $MSe = .59$]. This confirmation of changes in the bias of the global contextual components is a necessary condition for the predictions, based on these changes, of recall of the words repeated between the lists.

Analysis of recall of words repeated between the lists (Figure 4) reveals main effects for delay of final recall [$F(1,80) = 18.58$, $MSe = 1.21$] and within-lists counterbalancing [$F(4,80) = 3.69$, $MSe = 1.21$]. The between-lists lag (list serial position) did not contribute, by itself, any significant variability ($F < 1$). The important prediction is that, given the changes in the bias of the global contextual components indicated in Table 1, between-lists lag will interact with delay of final recall. Recall on the delayed final recall is predicted to be a monotonically increasing function of between-lists lag. Recall on the immediate final recall is predicted to be either a monotonically decreasing function of between-lists lag (Cue Type 1, Figure 1) or an inverted U-shaped function of the between-lists lag. To discriminate between the latter two possibilities, the interaction mean square is broken into orthogonal contrasts. Only the linear component of the interaction of between-lists lag and delay of final recall was significant [$F(1,240) = 6.13$, $MSe = .55$]. This result indicates that recall on the immediate final recall is best described by Cue 1 in Figure 1, while recall on the delayed final recall is best described by Cue 3.

It should be noted that the results depicted in Figure 4 are not a simple consequence of the list serial position variable or retention interval. Suppose, for example, that the decrease in the immediate final recall function is due to forgetting of the information stored

Table 1
Proportions Recalled of Words Repeated Within the Critical Lists

Time of Final Recall	List Serial Position 3	6	8	9
Immediate	.11	.13	.13	.17
Delayed	.13	.11	.12	.11

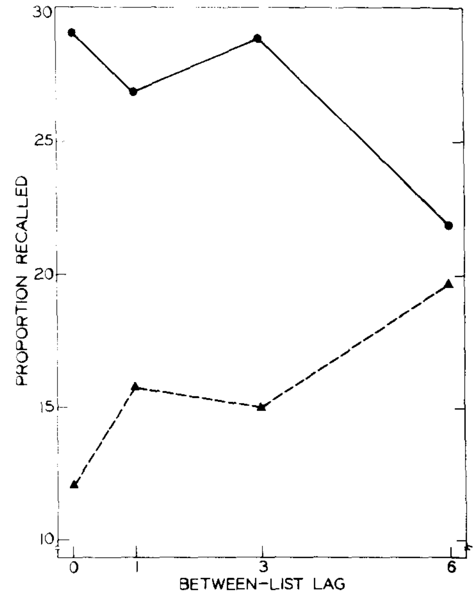

Figure 4. Mean recall of words repeated between lists on the final recall. The solid line represents immediate final recall; the dotted line represents delayed final recall.

at the first presentation, which has a retention interval positively correlated with the between-lists lag. This supposition cannot explain the increase in the delayed recall function. Neither can the increase in the delayed recall function be explained as a list-primacy effect; the first presentation of the longest between-lists lag condition is in List 3. Additionally, there is virtually no primacy effect indicated in Table 1. The best explanation of these results is that provided by component-levels theory. Differential storage of global contextual components and retrieval using global contextual components can be manipulated in ways directly analogous to the storage and retrieval of descriptive (Glenberg, 1976) and structural (Glenberg, 1977) components.

An interesting implication of these results is that, under the right conditions, there may be no limit to the improvement in performance that can be obtained by increasing the repetition lag. After short lags differential storage of descriptive components may have peaked, but differential storage of structural components is still continuing. After moderate lags, perhaps on the order of 20 to 40 intervening items in a free recall list, structural components have reached their limit of differential storage, but components of the global context may have not reached their peak differential storage. Hence, the theory can explain the effects of very long lags that have been found in free recall, and it predicts long lag effects in other situations where differential storage of contextual components could facilitate retrieval.

EXPERIMENT 3

Like Experiment 2, this experiment was designed to test predictions of the theory concerning the differential storage and retrieval of global contextual components.

The repetition lag, however, was not manipulated. Differential storage was directly controlled by changes in the stimulus conditions. Subjects viewed a single 40-word list in two experimental sessions separated by a 3-h interval. The sessions were held in either the same physical environment or different environments. Presumably, the former condition results in the storage of similar global contextual components at both presentations, while the latter condition results in traces containing different components representing both environments. Recall of the list was requested in a third session held 3 h after the second. The third session was conducted either in one of the old environments or in a new neutral environment dissimilar to the input environments.

The environment provides a source of global contextual components that are used to retrieve the stored information (S. M. Smith et al., 1978). Consider, for subjects who recall in the neutral environment, how those components interact with the stored global contextual information. The total pool of components shared by the neutral environment and both input environments is greater than the pool of components shared by the neutral environment and either input environment alone. Therefore, when the contextual components provided by the neutral context are the only retrieval cues, words studied in two different input environments will be more activated and better recalled than the words studied twice in a single input environment.

When recall is conducted in one of the original input environments, the global contextual components provided by the environment are biased; for the subjects who studied in two different environments, the contextual components match those stored at one presentation (the one in the test environment), but not those stored at the other presentation. The situation is analogous to that represented by Cue 1 in Figure 1 and the immediate final recall of Experiment 2. Recall in the biased test context will not favor the subjects who study the list twice in different environments. The operation of the theory is too inexplicit, however, and our measurement of environmental similarity is too crude to confidently predict that subjects who study the list twice in the biased test environment will recall more than the subjects who study the list twice but only once in the test environment.

In summary, the theory predicts an interaction between the input environment (same or different) and the test environment (biased or neutral). It is also likely that recall in the neutral environment will be inferior to recall in the biased environment. That is, the total number of components available in the neutral environment and included in the traces may be less than the number of components available in the biased (old) environment and shared by the traces.

Method

Subjects. A total of 64 subjects was drawn from the student population at the University of Wisconsin–Madison. The participants were paid $3 for their time or could use the experience as one way of fulfilling an introductory psychology course requirement.

Materials and Design. Three environmental contexts were used. Room A was located on the fifth floor of the Brogden Psychology Building. It was decorated to look like a laboratory. The room contained a computer and assorted peripheral equipment. The subject sat in a soundproof booth in the room. The booth was approximately 6 x 6 ft and contained a chair, desk, computer terminal, and various small pieces of equipment directly in front of the subject. In this context the stimuli were presented auditorily via a tape recorder.

Room B was in the basement of the same building and appeared more like an office than a laboratory. The floor was carpeted, the walls were decorated with posters, books and plants were in the room, and the lights were partially concealed behind a brightly colored print sheet. The room also contained chairs, tables, and cabinets. Stimuli were presented visually, on slides, in this context.

Room N, the neutral environment, was located on the second floor of the building. This room had bare walls and floor and contained only combination desk-chairs.

The four major conditions were formed by the factorial combination of two levels of input context (same or different) and the test context (biased or neutral). A total of 16 subjects was assigned to each major condition. In the same input context/biased test context condition, the order of the contexts in which the three sessions were conducted was AAA for eight subjects and BBB for eight subjects. For the subjects in the same input context/neutral test context condition, half received the AAN order and half the BBN order. In the different input context/biased test context condition, four subjects were assigned to each of the context orders ABA, ABB, BAA, and BAB. The context orders for the different input context/neutral test context condition were ABN and BAN, which were used equally often.

All subjects studied the same list composed of 40 common, single-syllable four-letter nouns. The first five and last five words were treated as primacy and recency buffers, respectively, and were eliminated from the data analysis.

Procedure. All subjects were met at a waiting room on the third floor of the building, and then they were escorted to the first room. The subjects were instructed that they were to study the list of words for a test. The words were presented one at a time at a 3-sec rate, either visually (Room B) or auditorily (Room A). Immediately following this presentation, the subjects were instructed to rate each word in terms of its affective value on a continuum from good to bad. The same list was again presented in the same modality at a 10-sec rate, during which the subjects rated the words. The subjects were dismissed after rating the words. The affect rating was used to insure adequate memory for the words and to give the session a sense of closure so that subjects would not actively rehearse the words between sessions. They were not informed that they would be required to recall the words at a later session.

Three hours after the first session, the subjects were met at the third-floor waiting room and escorted to either the same or a different context. The same procedure (two presentations of the list) was followed.

Three hours after the second session, the subjects were again met on the third floor and escorted to either a biased (A or B) or neutral (N) context. They were given 10 min to free recall the words.

Results and Discussion

The means of the four major conditions are presented in Table 2. Statistical analysis consisted of a 2 (input context) by 2 (test context) by 2 (Room A or Room B first) analysis of variance. Recall by the subjects whose first sessions were in Room A (.67) was superior to recall by the subjects whose first sessions were in

Table 2
Proportions Recalled of Repeated Lists

Text Context	Input Context	
	Same	Different
Biased	.64	.62
Neutral	.54	.63

Room B (.54) [$F(1,56) = 28.20$, $MSe = 8.94$]. This counterbalancing effect did not interact with any other variable and will not be considered further. The main effect of test context did not reach standard levels of significance [$F(1,56) = 2.94$, $p < .09$], although the means were ordered as predicted.

The critical result is the Input Context by Test Context interaction. This effect was significant [$F(1,56) = 4.55$]. Recall after studying in two different environments was superior to recall after studying in a single environment, when tested in a new environment. Nonetheless, variability in the study environments does not affect recall when tested in one of the original study environments. In terms of component-levels theory, differential storage of the global contextual components facilitates recall when retrieval is based on unbiased contextual components. On the other hand, when retrieval is cued with biased global contextual components, the effects of differential storage are modified as predicted.

One objection to the foregoing summary is that the effects attributed to the global context may be due to differential storage of components on many levels. That is, studying in two different environments may have led to greater differential storage of contextual, structural, and descriptive components than studying twice in the same environment. This objection, however, will not explain the interaction. Assume for a moment that more structural components were stored in the different input context conditions than the same input context conditions. This advantage would account for the difference in recall when tested in the neutral context. The objection predicts the same difference, however, when recall is requested in a biased context. That is, the variability in the structural components should manifest itself in an identical manner in both test contexts.

In conclusion, this experiment, along with Experiment 2, has demonstrated that manipulations at the level of the global context have effects analogous to the effects of similar manipulations of the local context (Experiment 1), structural components (Glenberg, 1977), and descriptive components (Glenberg, 1976). Differential storage at any level sets an upper bound on performance. The components in the retrieval cue control the level of performance within this bound.

GENERAL DISCUSSION

Comparison to Other Explanations of Spacing Effects

Component-levels theory as currently formulated provides a qualitative explanation for the effects of spacing on recall and recognition of repeated events. In addition, the theory generates a number of testable predictions and suggests methods for testing the theory, as well as allowing for expansion in many directions. This explanatory power has been purchased, however, at the expense of simplicity. Predictions depend on considering a number of sources of information during input processing, the mode of processing, changes on both of these dimensions during the repetition interval and at successive presentations, sources of information at testing, retrieval processes, and how all of these factors interact. An important question is whether this theoretical expense buys any explanatory advances over simpler accounts.

Consider an encoding variability theory based only upon the descriptive components. This sort of theory could certainly account for all of the phenomena that component-levels theory can predict on that one level, including those found in the recognition and paired associate paradigms. The single-level theory can also be stretched to include the relatively straightforward findings in other paradigms. It fails, however, when considering interactions between levels of components and interactions on levels other than the descriptive components. For example, Glenberg (1977) found that the monotonic lag effect in free recall is modified by the retrieval environment. The monotonic function could be described as reflecting differential storage of descriptive components, making the traces easier to retrieve, recognize, or decode. It is difficult to see, however, why, in such a model, providing input words that were adjacent to the repeated words would modify the shape of the lag function. To account for such a finding, the model must represent interitem relations. Similarly, the single-level encoding variability model could predict that cuing recall with the stimuli in the varied condition of Experiment 1 would eliminate the spacing effect. The reinstatement of the effect under free (contextually cued) recall would, however, pose a mystery for the model. The single-level structural model would fare no better in accounting for these data.

A single-component model based on the contextual components does better than the other single-level models (see Hintzman, 1976). Part of the superiority is due to contextual components being themselves aligned on a dimension (from local to global) that encompasses a range of cues varying in generality. Nonetheless, the contextual dimension alone fails to explain between-levels interactions. For example, in Experiment 1, the distributed practice effect demonstrated in free recall can be taken as evidence for the differential storage of contextual components. The single-component contextual model could then explain the interaction between varied-constant presentation and distribution in cued recall in one of two ways. First, the model could propose that the retrieval cues used in cued recall obscure the differential storage of the contextual components. This proposal, however, cannot account

for the distributed practice effect in the constant presentation, cued recall data. Alternatively, the model could propose that the varied presentation induces maximum encoding variability. This notion accounts for the interaction in cued recall, but it incorrectly predicts the same interaction in free recall. That is, if varied presentations induce maximum encoding variability of contextual elements that eliminates the distributed practice effect in cued recall, then the varied presentations should also eliminate the distributed practice effect in free recall.

Component-levels theory also compares favorably to the many "deficient processing" explanations (Hintzman, 1976) of distributed practice effects. As a class, these explanations propose that performance following massed practice is depressed due to incomplete or inefficient processing compared to distributed practice conditions. Hintzman (1976) further classifies the theories by the locus of the deficient processing (on the second presentation or between the first and second presentations) and whether the processing deficiencies are due to voluntary or involuntary processes. None of these models considers retrieval processes. Therefore, they cannot predict the sorts of interactions seen in Experiment 1. For example, since the distributed practice effect is eliminated by varied presentations (in cued recall), we can assume that varied presentations eliminate the deficient processing. Therefore, these theories must incorrectly predict the absence of a distributed practice effect in free recall.

A third class of theories appears to be having some success at least in predicting a new type of spacing effect. These explanations depend on an analysis of the retrieval requirements during input, specifically, retrieval of the first presentation information at the time of the second presentation (i.e., study-phase retrieval). Thios and D'Agostino (1976) report that when retrieval of first occurrence information (the sentence context of an object phrase) at the time of the second presentation is encouraged, then a recall test produces a monotonic, increasing spacing effect. When the first presentation sentence is provided at the second presentation, the spacing effect is attenuated or eliminated. Whitten and Bjork (1977) report a similar phenomenon.

Thios and D'Agostino (1976) propose that the study-phase retrieval may modify the retrievability of the first presentation information when similar retrieval information is used at later tests. After a short spacing interval, study-phase retrieval of first occurrence information may be accomplished by a relatively easy, temporally directed backward scan. As the spacing interval increases, this type of retrieval operation becomes less effective, and study-phase retrieval begins to depend on a reconstructive process that attempts to match the encoding of the currently presented item with previous encodings. If it is assumed that later retrieval typically depends on this reconstructive retrieval, and that the reconstruction retrieval on the test is facilitated by study-phase reconstructive retrieval, then the monotonic lag effect is predicted.

This retrieval-based explanation is potentially capable of predicting many of the interactions between spacing and the retrieval environment when it is assumed that there is positive transfer between either type of study-phase retrieval and the corresponding test retrieval. For example, when testing recognition memory after a short retention interval, retrieval will be based on the backward-scan mechanism. Previous study-phase retrievals at short spacing intervals may facilitate the test retrieval, while previous study-phase retrievals at long spacings (where constructive retrieval is used) may not. Therefore, after a short retention interval, MPs are predicted to be recognized better than DPs. Recognition memory tested after a long retention interval may be based on constructive retrieval. The constructive retrieval practice during distributed study will facilitate retrieval at the delayed test, yielding the monotonic, increasing spacing effect.

This retrieval-based theory can only predict beneficial effects of the repetition lag when the retrieval process at the test is similar to that used during study. Only then will the retrieval practice benefit retrieval at the test. It is difficult, however, to reconcile this position with spacing effects in the typical free recall paradigm where the retrieval environment on the test is unlike the putative cue at the second presentation, the nominal stimulus itself.

Problems with Component-Levels Theory

The theory is vague and ill-specified on a number of points, partly because of our general ignorance about the workings of memory, and partly because the theory makes similar predictions regardless of the exact specification. One such area is in the definition of the components: why three components, why these specific components, are they different in kind, and which tasks and processes lead to the storage of which components? Essentially, the components are meant to represent a range of information stored in memory. Grouping these types into three levels may be a convenient fiction. The important points for the theory of repetitions are that (1) not all components show differential storage in the same input conditions, (2) performance is a function of the overlap between the stored information and the retrieval cue, and (3) this overlap changes as a function of the retrieval environment (essentially, Flexser & Tulving's, 1978, retrieval independence). Within these constraints, and within the constraints of our present state of knowledge, it makes little difference if there are three or many more types of components, or the exact nature of the components. Nonetheless, specifying a grouping of the components into three levels does have its advantages: It allows for ease of comparison to other theories of memory, and it provides contact between the theory and various paradigms for ease of testing the theory.

The theory does suffer from its vague approach to context. The theory makes use of the concept of

context in deriving predictions about encoding, storage, and retrieval, but nowhere is there a rigorous specification of what context is, or how it works. Unfortunately, this is a shortcoming of most theories of episodic memory. What is, perhaps, most strange in component-levels theory is the representation of context as discrete components of the episodic trace. This representation was chosen to allow the same retrieval processes to operate at all levels. The burden, however, is shifted to the storage processes. With the assumption that all aspects of the context (local and global) are automatically included in all traces, the theory is forced to create extremely cumbersome traces to represent even the most trivial events.

One solution to the problem is to assume that traces are embedded within a context rather than the reverse. That is, we remember events within the context of other events. These events may be combined into higher order episodes or schemata (Kintsch, 1978), or in an associative network (Anderson & Bower, 1973) to provide a global context. The translation can be completed by assuming that accessing the higher order episode provides access to the individual events within the episode, that the probability of accessing any given event is inversely related to the total number of events included in the episode (cue overload), and that the point at which an episode is accessed or entered influences which events will be retrieved (cue bias).

Although this embedding seems a natural representation of context, within component-levels theory it raises additional problems. Specifically, this proposal requires that each repetition be represented by functionally separate traces. This view is contraindicated. Johnston and Uhl (1976) conducted a test of a prediction from an encoding variability point of view that rules out the multiple-trace hypothesis. They assumed that the greater the encoding variability, the more effective the repetition. They used the subject's positive recognition response at the second presentation as an indication that similar encodings were activated at both presentations. If the subject responded negatively at the second presentation, it was interpreted as an indication of a large difference in the encodings. Therefore, those items not recognized at the second presentation should be variably encoded (essentially independently encoded and represented by two traces) and remembered well (if one ignores selection artifacts, and the possibility that the negative response may be due to not storing a representation at the first presentation). The opposite result was found: The items not recognized at the second presentation were recalled very poorly. Similarly, Madigan (1969) demonstrated that only items recognized as old on their second presentations contributed to the spacing effect in free recall.

Component-levels theory is not embarrassed by these results. In the theory, encoding variability is conceptualized as the addition of new information to the same functional locus or representation, not the creation of functionally separate traces. Nonetheless, this specification does not completely solve the problem. The theory does not explain how, at the second presentation, the trace representing the first presentation is found so that new information can be added. One could speculate about simple, automatic retrieval processes when both presentations are in the same list, but these speculations would not account for the results of Experiment 2, where the repetitions are between lists.

Ultimately, both single- and multiple-trace representations of repetitions may be necessary. A single multicomponent trace may be an adequate representation for within-lists repetitions and provide an explanation of Johnston and Uhl's (1976) results. A multiple-trace representation of repetitions may be necessary to account for the data generated by between-lists repetitions.

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NOTES

1. Schematic representations of similar notions are presented in Glenberg (1976) and in Landauer (1975). Landauer's scheme, however, illustrates retrieval of at least one of many functionally separate traces, each representing a single repetition. The present scheme illustrates retrieval of one trace that incorporates information from individual repetitions. Glenberg's (1976) illustration can be thought of as representing the descriptive components of the present theory.

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