

Rhyme and Reason: Analyses of Dual Retrieval Cues

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If and only if each single cue uniquely defines its target, a independence model based on fragment theory can predict the strength of a combined dual cue from the strengths of its single cue components. If the single cues do not each uniquely define their target, no single monotonic function can predict the strength of the dual cue from its components; rather, what matters is the number of possible targets. The probability of generating a target word was .19 for rhyme cues, .14 for category cues, and .97 for rhyme-plus-category dual cues. Moreover, some pairs of cues had probabilities of producing their targets of .03 when used individually and 1.00 when used together, whereas other pairs had moderate probabilities individually and together. The results, which are interpreted in terms of multiple constraints limiting the number of responses, show why rhymes, which play a minimal role in laboratory studies of memory, are common in real-world mnemonics.

The way in which properties of stimuli combine to predict behavior has been an active area of study. Dual-cue investigations using verbal material have studied associations (Cofer, 1968; Jenkins & Cofer, 1957), tachistoscopic and other forms of word recognition (Morton, 1969; Tulving, Mandler, & Baumal, 1964), context surrounding a missing word (Rubin, 1976), errors (Reason, in press), concepts (Hampton, 1987; Jones, 1982; Osherson & Smith, 1981), recall from very long-term memory (Bruce, 1980), pictures and their captions (Bahrick & Gharrity, 1976; Jones, 1978), autobiographical memories (Reiser, Black, & Kalamarides, 1986; Wagenaar, 1986), recall of words (Le Voi, Ayton, Jonckheere, McClelland, & Rawles, 1983; McLeod, Williams, & Broadbent, 1971; Nelson & Borden, 1977; Nelson & Garland, 1969; Solso & Biersdorff, 1975; Tulving & Watkins, 1975), and recall of sentences (Anderson & Bower, 1972, 1973; Foss & Harwood, 1975). Many studies have also investigated how the perceptual properties of stimuli are combined. Such studies address this issue in terms of *gestalt*, *integral*, *holistic*, or *configural* processing (Garner, 1978; Kohler, 1947; Lockhead, 1972; Monahan & Lockhead, 1977). Both the memory and the perceptual studies make the same troublesome point: Measures based on independent properties or features can provide adequate descriptions of behavior in some instances but fail in others. This article is an attempt to address this general puzzle for the problem of retrieval from long-term memory.

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Bruce (1980) posed the central question this way: "Consider a memory target and two retrieval cues X and Y. Consider further a double probe, cue X + Y, that combines the X and Y information. Can retrieval to cue X + Y be accurately predicted from a knowledge of retrieval to cues X and Y given separately?" (p. 276). By way of definition, let the target be T, the probability of cuing the target with X be $p(T|X)$, the probability of cuing the target with Y be $p(T|Y)$, and the probability of cuing the target with X and Y together be $p(T|X \text{ and } Y)$. If the answer to Bruce's question is yes, the problem will be said to have a *composite* solution, and Equation 1 will hold:

$$p(T|X \text{ and } Y) = f(p(T|X), p(T|Y)). \quad (1)$$

We begin by reviewing the literature to demonstrate that stochastic independence has often been misapplied in attempts to formulate a composite model but that a successful stochastic independence composite model can be formulated by using fragment theory (Jones, 1976). The model holds, however, only when each single cue uniquely defines its target. Next, in a series of three experiments, we explore the effects of using single cues that have more than one target and demonstrate that for such cues no single monotonic composite model can hold. In this demonstration we reject the usual $p(T|X \text{ and } Y) > p(T|X) + p(T|Y)$ criterion for integral, holistic, or configural effects because it assumes that the composite model must be based on stochastic independence or a similar assumption. Instead, we use a stricter criterion that applies to a wider range of models. The discussion extends these results to the role of multiple constraints in recall.

Notational Problems in Formulating Stochastic Independence Models

Several composite models have been proposed by psychologists to answer Bruce's question. The simplest model is the case in which the two cues function independently of each other. It most commonly appears in the form of Equation 2. However, for cuing studies this notation is not accurate.

Rather, what is needed is the probability of retrieving the target, T, given both the cues X and Y, or $p(T | X \text{ and } Y)$. If one assumes that $p(T | X)$ is independent of $p(T | Y)$, then substituting $T | X$ for X and $T | Y$ for Y in Equation 2 leads to Equation 3. This still is not the form of Bruce's question. It is an approximation to studies that use sequential cuing with two cues (e.g., Tulving & Watkins, 1975; Watkins & Tulving, 1978) because they measure the probability of the target's occurring as a response to X or the target's occurring as a response to Y [i.e., $p(T | X \text{ or } T | Y)$] rather than the probability of the target's occurring as a response to the cue defined by X and Y occurring together [i.e., $p(T | X \text{ and } Y)$].

$$p(X \text{ or } Y) = p(X) + p(Y) - p(X) * p(Y) \quad (2)$$

$$p(T | X \text{ or } T | Y) = p(T | X) + p(T | Y) - p(T | X) * p(T | Y) \quad (3)$$

$$p(T | X \text{ and } Y) \neq p(T | X) + p(T | Y) - p(T | X) * p(T | Y). \quad (4)$$

One can write Equation 4 with an equal sign to summarize what many researchers have been implying and measuring in testing the independence hypothesis, but unlike Equations 2 and 3, it cannot be derived from the axioms of probability theory.¹ It is not as surprising, then, that Equations 2 or 3 do not fit empirical studies of cuing (e.g., Bruce, 1980; Jones, 1976) when they are tested by studies that actually measure $p(T | X \text{ and } Y)$.

Other equations have also attracted attention (Bruce, 1980; Jones, 1987). Equation 5 is the more general form of Equation 3 (Jones, 1987). By assuming stochastic independence, the last term of Equation 5 becomes $p(T | X) * p(T | Y)$, and Equation 3 results. By assuming *exclusivity* (i.e., only one cue can function at a time), the last term of Equation 5 becomes zero, and Equation 6 results. By assuming *redundancy* (i.e., one cue is always effective if the other cue is), Equation 7 results. Again, the problem is that none of these equations have the proper term, $p(T | X \text{ and } Y)$, on the left side, and so none of these equations are an answer to Bruce's question:

$$p(T | X \text{ or } T | Y) = p(T | X) + p(T | Y) - p(T | X \text{ and } T | Y) \quad (5)$$

$$p(T | X \text{ or } T | Y) = p(T | X) + p(T | Y) \quad (6)$$

$$p(T | X \text{ or } T | Y) = \text{the larger of } p(T | X), p(T | Y). \quad (7)$$

Fragment Theory

Instead of asking about a target, T, and two cues, X and Y, as do the models just discussed, Jones's fragment theory (1976, 1978, 1979, 1983), asks what fragments would be retained in memory after exposure to the target and two cues. This change, which explicitly includes the target with the cues, provides an equation based on stochastic independence (as is done here) or exclusivity (as was done by Jones) that can be solved for $p(T | X \text{ and } Y)$. Thus, as presented here, fragment

theory is an application of the stochastic independence model, but unlike Equations 2 through 7, it measures the probability of retrieval given two cues presented together [i.e., $p(T | X \text{ and } Y)$].

For a single presentation of the target plus two cues (i.e., T and X and Y presented together), none or one of the following fragments would be stored in memory: T-X-Y, T-X, T-Y, X-Y, T, X, or Y. For example, a single presentation of the stimulus *a cup colored yellow located at the middle of the display* would lead to either nothing or one of the following seven fragments being stored in a subject's memory: *cup-yellow-middle* (T-X-Y), *cup-yellow* (T-X), *cup-middle* (T-Y), *yellow-middle* (X-Y), *cup* (T), *yellow* (X), or *middle* (Y). If only the T-X-Y fragment were stored, then the cues X and Y, X, or Y would result in the target's being recalled because for these three cues a component of the cue and the target would both be in the fragment. If only the T-X fragment were stored, then the cues X and Y, or X, but not the cue Y, would result in the target's being recalled because the target and components of the first two cues, but not the third, would be in the fragment. If none of the first three fragments were stored, then the cues X and Y, X, and Y could not retrieve the target because, for each of the remaining four fragments, a component of the cue and the target would not both be in the fragment.

By enumerating all the fragments that could be in memory and each possible response to a cue, fragment theory produces a quantitative model of the effects of multiple cues. In particular, fragment theory predicts that the probability of the combined cue, X and Y, retrieving the target, T, is equal to the probability that the fragment T-X or the fragment T-Y or the fragment T-X-Y is in memory minus some terms that are needed to ensure that more than one retrieval is not counted if more than one fragment exists in memory. Assuming all fragments are independent (i.e., two or more fragments, such as T-X and T-X-Y, could exist in memory and function without affecting each other), Equation 8 results. The equation is derived from extending the independence Equation 2 from two events, X and Y, to three events, T-X, T-Y, and T-X-Y. If the stimulus were presented only once, only one fragment could be stored, and all but the first three terms of Equation 8 would become zero, which is what would result if exclusivity were to replace the independence assumption in Equation 8.²

¹ For example, Equation 4, if written with an equal sign, would have a curious property when the occurrence of the target is independent of the cues. By the definition of independence $p(T | X \text{ and } Y) = p(T | X) = p(T | Y) = p(T)$. That is, if T and X occur independently, the probability of T's occurring, given that X occurred, is the same as the probability of T's occurring. Substituting $p(T)$ for all the conditional probabilities in Equation 4 yields $p(T) = p(T) + p(T) - p(T) * p(T)$, which reduces to $p(T) = p(T)^2$, an equation that is true only when $p(T)$ equals zero or one.

² Jones assumes that for each presentation of a stimulus only one fragment is stored, and therefore the probability of any two fragments being in memory is assumed to be zero [i.e., $p(\text{fragment, and fragment}) = 0$]. This is equivalent to exclusivity (Jones, 1987) as opposed to independence among memory fragments and greatly simplifies the

$$\begin{aligned}
 p(T | X \text{ and } Y) &= p(T-X \text{ or } T-Y \text{ or } T-X-Y) \\
 &= p(T-X) + p(T-Y) + p(T-X-Y) - [p(T-X) * p(T-Y)] \\
 &\quad - [p(T-X) * p(T-X-Y)] - [p(T-Y) * p(T-X-Y)] \\
 &\quad + [p(T-X) * p(T-Y) * p(T-X-Y)]. \quad (8)
 \end{aligned}$$

Equation 8 can be put into a composite form by resolving the terms on the right side of the equation into functions of $p(T | X)$ and $p(T | Y)$. This can be accomplished by using data from successive cues (e.g., Bruce, 1980). The calculations follow Tulving and Watkins's (1975) reduction method, which is mathematically equivalent to fragment theory for the purposes of estimating parameters (Bruce, 1980; Le Voi et al., 1983), though it makes fewer testable claims about the effect of combined cues (Ogilvie, Tulving, Paskowitz, & Jones, 1980; cf. Le Voi et al., 1983). Thus, by using fragment theory, parameters estimated from single cues can account for the retrieval to dual cues.

Five studies in which fragment theory predicts dual cuing are reviewed: Bruce (1980), Jones (1976), Jones (1978), Watkins and Tulving (1978), and Tulving and Watkins (1975). Then we return to these same five studies and provide situations in which fragment theory would not predict dual cuing. The purpose of this review is to argue (a) that Equations 2 through 7 are not only theoretically flawed for dual cuing but also that they fail empirically, and (b) that each single cue must have only one target if a composite model, such as fragment theory, is to predict dual cuing.

Five Studies That Support Fragment Theory

In Bruce's (1980) experiment, there was no study phase in which new learning took place; rather, the names of 32 famous people were cued with facts about their lives. For example, Will Rogers (the target, T) was cued by "This person said 'I never met a man I didn't like'" (cue X) and "This humorist was killed in a private plane crash" (cue Y). The cues were given either individually in successive lists or in pairs in the same list. If cue X but not cue Y worked individually for a given subject, then the fragment T-X must be stored, but not the fragments T-Y and T-X-Y. If both cues worked individually, then either of the following sets of fragments must be stored: (a) T-X-Y alone or with one or both of T-X and T-Y or (b) both T-X and T-Y. Using Tulving and Watkins's (1975) reduction method to make the estimates, Bruce found a good fit to fragment theory (Equation 8) but not to the independence model (Equation 4 with an equal sign) or to the redundancy model (Equation 7).

mathematics of fragment theory. We have made an unauthorized extension of fragment theory from explaining cuing of stimuli presented once in the laboratory to stimuli presented many times under various conditions. Although we can maintain Jones's assumption that only one fragment can be stored for each presentation, we must allow for more than one fragment to reside in memory for any given stimulus that was presented more than once [i.e., $p(\text{fragment}_i \text{ and } \text{fragment}_j) \geq 0$]. We therefore can no longer assume exclusivity and replace it with stochastic independence among fragments in memory.

Jones's (1976) initial experiments on fragment theory used the *yellow cup located at the middle* stimulus mentioned earlier. There were nine sets of nine slides. Each of the nine slides contained one of nine objects in one of nine colors in one of nine locations. Each object, each color, and each location was used only once in a set, and each color-object-location combination was used only once in the nine sets. After seeing a set of nine slides, subjects were cued with some portion of the triplet from one slide and asked to recall the other component(s). Jones also included the order of presentation within a set as a component, but this variable was qualitatively different from the other three and is not discussed here. For the color-object-location triplets, fragment theory provided an excellent account of the cuing data. The independence model (Equation 4 with an equal sign) did not.

Anderson and Bower (1973) had subjects learn sentences of the form location-subject-verb-object or subject-verb₁-object-verb₂-location and then cued recall of the sentences with various components either alone or in combination. Jones (1978) reanalyzed Anderson and Bower's sentences in terms of location-subject-verb-object or subject-verb₁-object-verb₂-location fragments. Fragment theory provided a better fit to the data than did the HAM (human associative memory) model (Anderson & Bower, 1973), for which the data were originally collected (Anderson & Bower, 1980, p. 237; Jones, 1978).

Watkins and Tulving (1978, Experiment 2) had subjects learn and recall a list of 25 words. They then presented the subjects with a list of 25 single cues and finally with either a list of an additional 25 single cues or a list of 25 dual cues, each dual cue formed by pairing two of the single cues. The words to be learned were strong associates of the cues. The results of the sequential presentation of single cues were consistent with the reduction method and therefore with fragment theory. No matter whether words recalled in the free recall task were included in the analysis or not, the first and second single cues produced approximately the same level of recall.

Tulving and Watkins (1975) gave their subjects lists of 16 words. On one list a word would be paired with a rhyme cue and on a different list that word would be paired with an associative cue. The subjects were asked to study each pair. The data reported are for the subjects' recall when cued sequentially with two new cues, either a different rhyme cue or a different associative cue. That is, the cue used for retrieval was of the same kind but not identical to the cue studied. Tulving and Watkins found that their reduction method, and therefore fragment theory, worked well to describe the data.

In summary, in the five studies reviewed here, fragment theory consistently predicted the data and did so where competing theories based on Equations 2 through 7 failed. The stimuli and targets in these studies, however, all share a crucial property. The individual stimuli lead to only one target in the retrieval set. We will call this a *unique* cue to target relation. Jones noted similar limitations to his theory by using the concept of *independence* and the concept of *intrinsic* versus *extrinsic* knowledge. According to Jones (1978, p. 78), fragment theory is intended to be applied only in situations where

the target and the cues are “independent”; but as will be shown as we examine the same studies again, it is uniqueness and not independence that matters. Jones’s second distinction—that between associations that are extrinsic, or external and prior to the experiment, and those that are intrinsic, or part of the experiment—is also an attempt to rule out nonunique relations. Again, it will be shown that it is the uniqueness of the associations and not where they were learned that is crucial. A reexamination of the five studies will demonstrate these points by showing that when there is not a unique cue to target relation, even intrinsic learning violates fragment theory; and when there is a unique cue to target relation, even intrinsic material does not violate fragment theory.

Five Studies With Nonunique Cues That Would Not Support Fragment Theory

Returning to Bruce’s (1980) experiment, note that the names of famous people were cued with facts about their lives that can be assumed to identify uniquely a target-person in the subjects’ memory, just as the cue *yellow* would identify uniquely *cup* in Jones’s (1976) experiment. For instance, Will Rogers was cued by “This humorist was killed in a private plane crash.” That is, Bruce’s individual cues are unique even though the cue to target relation was learned outside the laboratory and is therefore extrinsic in Jones’s terms.

If Bruce had used cues like “A humorist” and “Killed in a private plane crash,” which are still examples of extrinsic learning, fragment theory would not have predicted the results because each cue could be used for more than one possible target-person and thus would not be unique. For instance, a subject might know a dozen famous humorists and a half dozen famous people who were killed in a plane crash but only one person who fit both criteria. Giving a subject two of these modified cues would increase the number of potential fragments that would lead to correct recall, but it would also decrease the number of reasonable responses that a subject could give to the dual, as opposed to the single, cues. It is precisely to avoid this second factor that fragment theory requires a unique target for each cue. Thus, Bruce’s experiment with his original stimuli supports fragment theory by using unique cues with extrinsic as opposed to intrinsic material. In contrast, the hypothetical experiment proposed here with nonunique, but still extrinsic, stimuli would not support fragment theory.

Jones’s (1976) color-object-location study refers to stimuli with unique cue to target relations as stimuli having independent attributes, but the attributes are not independent. Rather, the attributes are redundant (e.g., knowing the color determines the object and the location), and they have to be if each cue is to have a unique target. Thus the stimulus attributes presented to the subjects are not independent, even if Jones chose among independent dimensions in preparing the stimuli. Moreover, the last stimulus in each set of nine is determined before it is presented because each attribute is used once and only once, leaving only one choice of color, object, and location free to be combined. Jones’s presentation

of nine sets of nine stimuli does not remedy the problem. If enough trials were run, the entire last set of nine stimuli would be determined by the earlier sets. The stimuli could have been designed so that each set of nine stimuli contained many yellow objects or many cups in different colors. For cases like these, fragment theory explicitly does not hold and would fail to predict the data. This is so because the cue to target relation is not unique, not because the cue and target failed to be independent. Our claim is that fragment theory really requires that there be only one target for each single cue.

Fragment theory predicts a symmetry in cuing among all components of a fragment; all components of a fragment are assumed to be equally effective in cuing other components. Fragment theory therefore predicts that targets and cues are interchangeable. This distinctive and testable assumption of fragment theory, though it is not central to our main point and though it on occasion appears to be false (Anderson & Bower, 1980, p. 237; Rubin, 1983), is maintained in order to explore the pervasive role of uniqueness. In particular, we claim that the symmetry assumed by fragment theory can hold only if all possible cues in a stimulus (i.e., all components) are uniquely related to all possible targets (i.e., all other components), which implies that each component can appear in only one stimulus. When a component appears in more than one stimulus, a unique cue to target relation can be broken by interchanging the roles of target and cue. In such cases, it is uniqueness, not symmetry, in cuing that is the prevailing principle; if the role of target and cue are interchanged, the theory will fail if and only if nonunique cue to target relations are created.

Fragment theory can account for cuing better than can competing theories when there are many cues with the same target (e.g., when $\text{subject}_1\text{-verb}_1$ and $\text{subject}_2\text{-verb}_2$ both have a unique target, object_1 , Jones, 1978), but fragment theory cannot predict well when there is a cue with many targets (e.g., reversing the role of targets and cues in the previous example so that object_1 cues both $\text{subject}_1\text{-verb}_1$ and $\text{subject}_2\text{-verb}_2$). Similarly, fragment theory does not work when the same word is used as a cue in three sentences (Jones, 1978, pp. 362–363). If cues have more than one target, then not only does combining cues increase the number of fragments leading to retrieval, but also it can reduce the number of possible targets satisfying both cues. Fragment theory is not intended to account for this second factor.

Thus, as long as there is a unique target for each cue, multiple cues cannot serve to limit the number of possible targets, and a composite model—fragment theory—can account for the data. Issues of independence, intrinsic versus extrinsic learning, and the symmetry of all components in cuing a fragment are secondary to this principle.

The importance of having only one target for each cue is made especially clearly in the Watkins and Tulving (1978) study because even with identical stimuli, a small change in the procedure changes the results. The study was done in order to test the underlying assumptions of the Tulving and Watkins (1975) reduction method, and therefore, for our purposes, fragment theory. The reduction method analyzes memory traces by using two cues to prompt the recall of a

single target word. In the reduction method, the two cues are not presented together, and the subjects do not know that the two cues are intended to cue the same target word. In this procedure, the cues are assumed to be unique, and fragment theory holds. If, however, the same stimuli are used but the two cues are presented simultaneously so that the subjects know they refer to the same target, the reduction method and fragment theory typically do not hold. This case was first reported by McLeod et al. (1971) and confirmed by Watkins and Tulving (1978). When the first cue was presented again with the second cue, the second cue was much more effective than when the second cue was presented alone.

In the McLeod et al. and Watkins and Tulving studies, free recall was measured in addition to two cued recalls, making it possible to assess the effectiveness of cuing in the single cue condition and with it to predict a baseline level for recall after two sequential cues. McLeod et al. (1971) derived a composite model by assuming a free recall task followed by two stochastically independent cues of equal cuing strength. We applied their model to the Watkins and Tulving (1978) data. When the two cues were presented separately, a reasonable fit of the predicted and expected probability of recall after two cues was obtained (.586 vs. .536, respectively). However, when the two cues were presented simultaneously, the model predicted .467 on the basis of single cue strength, underestimating the observed value of .618.

Why is there a difference in the same experiment between presenting the second cue alone as opposed to presenting it with a re-presentation of the first cue? Both cues are associated with many words in addition to the target word, so they are not unique cues in the same way that Bruce's or Jones's cues are uniquely related to their targets. The cues do, however, have a unique, or nearly unique, target in the recall list because the chance of any other strong associate being in the recall list is negligible. When the second cue is presented alone, it has a unique, or nearly unique, target in the recall list, but the probability of retrieving that target is small because there are so many alternative associates not on the list. When the second cue is presented with the first, the set of all words with which both cues are jointly associated is much smaller, making the probability of retrieving the target larger. Although other explanations exist (Watkins & Tulving, 1978), for the sake of parsimony, the same reduction-in-target-set-size explanation is being offered here as was offered for the hypothetical changes made in the Bruce and Jones studies.

When Tulving and Watkins (1975) presented rhyme and associative cues sequentially, their data supported fragment theory. What would happen if their cues were presented together? If the analysis given here is correct, then fragment theory should fail to hold to the extent that the target set size is reduced by the joint cue. The experiments that follow will test this notion.

Experiment 1: Dual Cuing With Nonunique Single Cues

Tulving and Watkins's (1975) rhyme and meaning cues are good cues to demonstrate our argument because, as anyone who has tried to write poems with rhymes knows, there are many words to express a particular meaning and many words to express a particular rhyme, but few, if any, words that can

express both the meaning and the rhyme. This intuition is supported by the results of observations made on the causes of stability in several oral traditions. The genres of epic poetry, children's counting-out rhymes, and North Carolina ballads indicate that there are regularities in the choice of rhyme and meaning that operate to limit the possible choices of words or phrases (Kelly & Rubin, 1988; Rubin, 1981; Wallace & Rubin, 1988a, 1988b). Moreover, these various forms of organization, or constraint, do not appear to operate independently, but rather function in a highly interrelated fashion that results in more constraint than would be expected from the independent combination of the individual forms of organization.

It needs to be noted, however, that sound pattern and meaning are not interrelated in all tasks. The sound pattern and the meaning of words are distinct properties of stimuli in that one seldom tells anything about the other (Brown, 1958; Taylor & Taylor, 1965). In fact, one of the distinguishing features of language is that sound is arbitrarily assigned to meaning (Hockett, 1963). However, properties that are independent in one sense or behavior need not be independent in another.

In addition, because the focus of this article is on how cues combine and not on rhyme per se, we group together, under the term *rhyme*, effects caused by the sound pattern and the orthography of rhyme. Although separating the contributions of sound and orthography are often important (Kelly & Rubin, 1988; Seidenberg & Tannenhaus, 1979), they are not important for the theoretical arguments or the practical extensions discussed here.

Like Tulving and Watkins (1975), we do not cue a target word with a previously studied cue. Unlike Tulving and Watkins, we do not use a study phase, but rather test retrieval from very long-term memory as did Bruce (1980). There are two reasons for this choice. The first is that because we want a violation of fragment theory, we do not want the single cues to be unique in any sense, and having the target words in a study list could cause the retrieval cues to be uniquely related to the words in the to-be-remembered list. The second reason is that we want to minimize the chances of retrieving a word because it has recently been studied so that the effects of the restriction of set size on retrieval can be as large as possible.

Method

Materials. McEvoy and Nelson's (1980) rhyme norms were searched for target words that occurred either as a first associate in Battig and Montague's (1969) norms or in the category name section of McEvoy and Nelson's (1982) semantic category norms. Target words were included only if they had an observed frequency of 2 or more times per 100 both in the rhyme norms and in at least one of the two meaning norms. In this way, idiosyncratic responses were eliminated, and the target words could be assumed to be reasonable responses to their cues even if they were not generated by the subjects in Experiment 1.

If several words fit the same pair of rhyme and meaning categories, one of the words was randomly selected to be the target word. This search resulted in 169 target words from 125 different rhyme categories and 82 different meaning categories. One pseudo-random order, and the reverse of that order, was made for the 125 rhyme-category cues, for the 82 meaning-category cues, and for the 169 dual

cues. In the dual-cue order, no two instances of the same rhyme or meaning category were adjacent.

Tape recordings of the cue lists were made by a Duke undergraduate from North Carolina. Instructions were on the cover of the typed response booklets. The tapes contained only the rhyme sound presented twice for the rhyme cue (e.g., *ed, ed*), the category name for the meaning cue (e.g., *a color*), or the repeated rhyme sound followed by the category name for the dual cue (e.g., *ed, ed, a color*). The tapes allowed 10 s for subjects to respond with a word that fit each cue.

Procedure. The 127 Duke undergraduates, who were tested in large groups, heard either the dual-cue tape ($n = 67$) or both the rhyme and meaning single-cue tapes ($n = 60$) and responded to each cue with an appropriate word. Subjects were assigned randomly to the dual-cue or single-cue condition, the forward or reverse order tape, and, in the single-cue condition, the rhyme/meaning versus meaning/rhyme order.

Results

It was necessary to obtain the same number of responses to each word in order to do the set size analysis that follows. Data were therefore scored until 50 valid responses were obtained for each cue. An undergraduate employee judged valid responses by using the McEvoy and Nelson (1982) norms as a guide and removed all responses that were misinterpretations of the rhyme or the meaning category cues. Because of ambiguities in pronunciation, several rhyme categories failed to produce 50 valid responses. For example, as said by many North Carolinians including our speaker, the words *tin* and *ten* sound identical. When the problematic rhyme categories were removed, 110 target words remained.

The observed probabilities of responding with the target words, given the rhyme, meaning, and dual cues, were .192, .142, and .973, respectively. The observed effect of dual cuing greatly exceeds what usually would be expected from the independent strengths of the single cues. Under any of the models considered in the introduction (i.e., Equations 2 through 8), it would be at most .334.

Experiment 2: A Second Demonstration

The results of Experiment 1 are striking enough to warrant repetition with a new set of stimuli and a slightly different task. Fisher and Craik (1977) found a set of 54 target words that could be cued with either a rhyming word or a semantic associate. Half of their subjects were given 10 s to record as many different words as they could that rhymed with each cue; the other half were given 10 s to record as many semantic associates as they could. On the average, their subjects listed approximately three words for each cue. The probability of a target word's appearing during the 10-s interval for both the rhyme and associative cues was .165, so a reasonable estimate that any single response would be the target word is $.165/3$, or .055. All that is necessary to complete an analysis similar to that of Experiment 1 is a dual-cuing condition.

Method

Thirty-five undergraduate subjects were each given a typed list of 54 double cues. The first column was labeled "brought to mind by," the second column was labeled "rhymes with," and the third column contained blanks. Unlike the Fisher and Craik norming procedure, only one response was requested. Examples of associative cues, rhyme

cues, and their target words include *mirror, pass, glass; oil, peace, grease;* and *sing, rant, chant*.

Results

Approximately 3% of the blanks had no responses and were, therefore, not included in the calculations. If the Fisher and Craik data and any of the models considered in the introduction (i.e., Equations 2 through 8) are used, the dual cue would be expected to produce the target words with an average probability of not more than .110. The observed average dual-cue probability was .865. In spite of differences in materials, procedures, and subjects, Experiment 2 substantiates the basic finding of Experiment 1. Moreover, the extent to which dual cues exceed what would be expected from their component single cues is much larger in Experiments 1 and 2 than in any of the studies cited in the introduction.

Analyses of Set Size

What could be causing this marked violation of fragment theory? If the analysis of the literature presented in the introduction is correct, then the cues must not be uniquely specifying their targets. Figure 1 presents some hypothetical relations between a rhyme category, *-at*, and three meaning categories—*parts of a tree, items of clothing, and animals*. For Panel a, there is no overlap in the rhyme and meaning category, and dual cuing can produce no responses. For Panel b, one word is common to both categories so the dual cue uniquely specifies its target, but the single cues do not. For Panel c, more than one word is common to both categories. For both Panels b and c, there is a marked decrease in the number of responses a cue can elicit that are not the target as one goes from the single to the dual cue, and so the probability of responding with the target should go up markedly with the dual cues. This argument is identical to the one used to discuss the five studies reviewed in the introduction. Panel d shows what happens for unique cues like Jones's *yellow-middle-cup* example. There would be only one target word in the figure, *cup*, and it would be in both of the categories—*yellow* and *middle*—and therefore in their intersection. This is not what happens with rhyme and meaning category cues.

A Set Size Analysis of Experiment 1

The data from Experiment 1 allow a set size explanation to be examined quantitatively. Set size is the number of different responses a group of subjects gives to a cue (Nelson, 1981). For Experiment 1, the set size is the number of different words that were given out of 50 responses. For the rhyme cues the average set size was 10.9 (range = 3–25; $SD = 4.3$). In Figure 1, this corresponds to the number of words in the *-at* rhyme category. For the meaning cues, the average set size was 12.4 (range = 3–30; $SD = 5.7$). In Figure 1, this corresponds to the number of words in the meaning categories in each panel. For the dual cues, the average set size was 1.3 (range = 1–3; $SD = 0.6$). In Figure 1, this corresponds to the words that fall in both categories (e.g., nothing in Panel a, *hat* in Panel b, and *rat* and *cat* in Panel c). In summary, in the two single-cue conditions, an average of 11 unique words out of 50

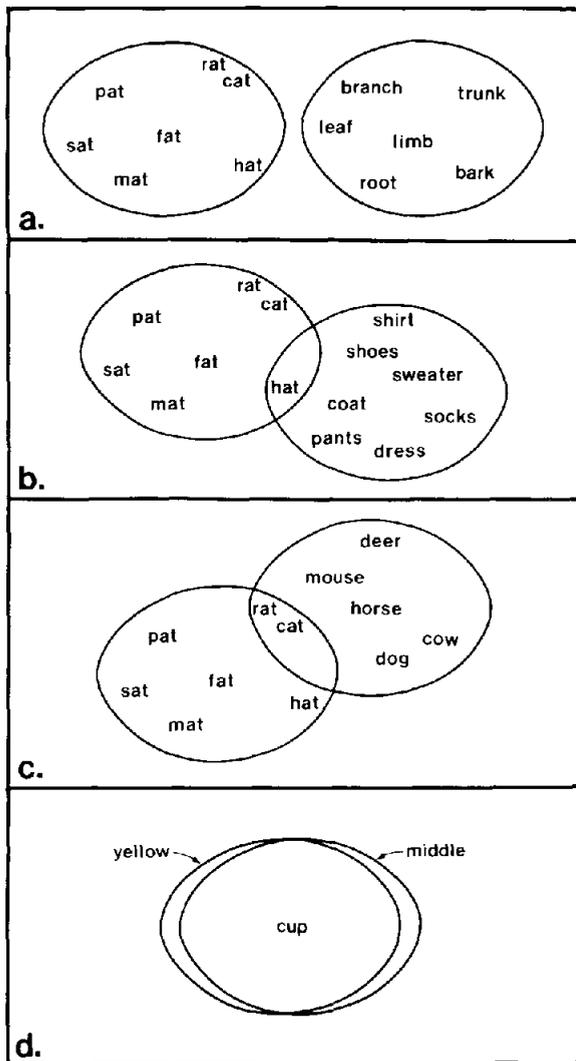


Figure 1. Three possible configurations of the overlap between a rhyme and a meaning category: no common words (Panel a), a single common word (Panel b), and multiple common words (Panel c), compared with the case of two single cues that each uniquely define their target (Panel d).

responses was given for each cue, with a maximum of 30 unique words out of 50 responses, whereas in the dual-cue condition, most cues produced the identical response for all 50 subjects, with a maximum of only 3 different words out of 50 responses. Moreover, this maximum set size for dual cues was achieved for only 6 out of the 110 dual cues. Thus, for dual cues, the set of responses is greatly reduced, and thus the probability of a response being the target is greatly increased.

An Examination of Set Size in Existing Norms

In order to assess the generality of this set size effect, two existing norms were reanalyzed for rhyme and meaning category overlap. This analysis of the existing norms is more

representative of dual cuing by rhyme and meaning than is the set size analysis that was based on the data from Experiment 1. In the Experiment 1 analysis, words were included in the sample only if they belonged to both a rhyme and a meaning category. Here words were sampled without regard to this property. Responses that subjects had given in the norms to a sample of rhyme cues and a sample of meaning cues were examined in order to see how many of the responses were present in both a rhyme and a meaning category. From this we estimated how likely it is that arbitrarily chosen rhyme and meaning categories share exemplars (i.e., how many pairs of categories are like Panels b and c as opposed to Panel a of Figure 1) and how many exemplars they will share (i.e., the set size or number of words that are in the intersection of the two categories in Panels b and c of Figure 1).

McEvoy and Nelson's (1980) norms of rhyme endings and McEvoy and Nelson's (1982) semantic category norms contain responses from approximately 175 undergraduates who were asked to list the first instance that came to mind for categories such as words that end with the sound *ing* or that are a *metal*. The norms list all responses, classifying them as valid or not valid category members. In order to include clearly defined categories of different sizes, the norms were initially divided into categories with a small, medium, and large number of different responses. Then the 15 small, 15 medium, and 15 large rhyme and the 15 small, 15 medium, and 15 large meaning categories with the largest proportion of valid responses per category were chosen. The mean number of unique responses (i.e., the set size) in the 15 small, 15 medium, and 15 large rhyme categories was 4.1, 14.6, and 28.4, respectively. For meaning categories the corresponding figures were 6.0, 12.9, and 28.1. Thus, on the average, the small categories each contained about 5 different exemplars, the medium categories about 14, and the large about 28.

Table 1 contains the number of category pairings for which at least one word existed in the norms that fit both the rhyme and meaning category constraint. For instance, in examining the cell for the large rhyme category and the large meaning category, we find that there are 7 cases in which words exist that satisfy both one of the 15 rhyme and one of the 15 meaning cues. The maximum number possible for this cell is 15×15 , or 225. That is, all 15 of the rhyme categories could have words that overlap with all 15 of the meaning categories. The cell for the large rhyme category and the small meaning category has 8 cases in which words exist that satisfy both one of the 15 rhyme and one of the 15 meaning cues. For this cell there were more than 15 words in each rhyme category but

Table 1
Number of Category Pairs With a Word Listed
in Both Categories

Meaning	Rhyme			Sum
	Small	Medium	Large	
Small	2	2	8	12
Medium	0	5	4	9
Large	3	7	7	17
Sum	5	14	19	38

an average of only 6 words in each meaning category. Assuming that each meaning word has only one pronunciation and thus could appear in only one rhyme category, the maximum number possible for the entry in this cell is 15×6 , or 90. As would be expected, the observed entries appear to increase moderately as the set size of the single-cue categories increases. Overall, the observed entries averaged 4.2, or about 3% of the maximum possible for each cell. That is, when arbitrary rhyme and meaning categories are paired, the same word or words are found in both categories in only 3% of the cases.

Of equal importance to the small number of rhyme and meaning categories that share common words is the set size of the particular category pairings that do share common words. Given that at least one word belongs to both a rhyme and a meaning category, how many words are there that belong to both categories? The answer for this sample is quite simple. The set size was always one, indicating that each double cue uniquely determined which word would be selected. Thus the set sizes of the individual categories were no better at predicting the set size of the two categories considered together than were the probabilities from the individual categories able to predict the probabilities from the categories considered together.

The pairing of 97% of the rhyme and meaning categories yielded no words from the norms that belonged to both sets (analogous to Panel a of Figure 1), and in the 3% of the cases in which such a word did exist, it was the only word (analogous to Panel b). There were no cases analogous to Panel c. Again, the dual-cue condition severely constrains the available responses, and so the remaining responses, if there are any, are much more likely to occur.

The constraining effect of the dual cues is large enough to hide any effects that could be attributed to fragment theory. In contrast, in Jones's study, the target, *cup*, was uniquely identified by either single cue, *yellow* or *middle*, as well as by the dual cue, *yellow-middle* (as shown in Panel d). In this case, fragment theory can predict the data because the single and dual cues both have the same number of possible targets, one, and thus there can be no effect of the relative set sizes of the single and dual cues.

Experiment 3: A Test of Composite Models

Given the results of the first two experiments, Equations 4 (with an equal sign), 6, 7, and 8 cannot predict the rhyme-plus-meaning dual-cue probability. Nonetheless, some other composite model might account for the data. Because there exist many other functions of the form of Equation 1 which share little in common mathematically, they cannot all be ruled out. We can, however, show that there is no single monotonic function of the form of Equation 1 that fits the data. The monotonic restriction is a weak restriction and one that is psychologically motivated. Increasing the strength of a cue in isolation should not decrease its strength when used with a second cue.

For composite Equations 2, 3, 4 (with an equal sign), 5, 6, 7, and 8, the largest value obtainable for $p(T | X \text{ and } Y)$ cannot exceed $p(T | X) + p(T | Y)$.³ Larger values of $p(T | X \text{ and } Y)$ have therefore been commonly taken as evidence

against a composite model (e.g., Bruce, 1980, p. 278; Foss & Harwood, 1975, pp. 8; Jones, 1978, pp. 363-364). However, larger values are not evidence against a composite model unless one adds that Equation 1 must be based on stochastic independence, exclusivity, redundancy, or on some other added assumption that leads to this inequality or a similar one. The reason that the term *composite* was coined here instead of the more common terms, *analytic* and *separable*, and the reason that the contrasting terms of *gestalt*, *integral*, *holistic*, and *configural* have been avoided is that the dichotomy between these two sets of terms is often decided by using the equation $p(T | X \text{ and } Y) \leq p(T | X) + p(T | Y)$, because most, if not all, of the analytic or separable models assume stochastically independent components. All composite models, however, need not follow the $p(T | X \text{ and } Y) \leq p(T | X) + p(T | Y)$ inequality.

The-whole-is-marginally-greater-than-the-sum-of-the-parts model, for which $p(T | X \text{ and } Y)$ equals the smaller of either 1.00 or $p(T | X) + p(T | Y) + .10$, is a composite model that predicts values that exceed the $p(T | X) + p(T | Y)$ limit. More serious composite models also exist that can exceed the $p(T | X) + p(T | Y)$ limit. These include the logogen (Morton, 1969) and the logit (Tulving et al., 1964) models. For situations in which any of these models hold, accurate component based predictions can be made. Moreover, models that are not composite can be devised that are consistently under the limit.

The whole class of composite models based on monotonic combinations of the probabilities could be challenged if, however, nonmonotonic data were produced. In particular, two pairs of cues are needed. In the first pair, the single cues each must have a low probability of cuing a target but must combine to yield a high probability of cuing their target. In the second pair, the single cues each must have a higher probability of cuing a target than did the first pair but must combine to yield a lower probability of cuing their target than did the first pair.

The 110 target words of Experiment 1 were searched to provide pairs of target words that fit the above criterion. Three such pairs of target words were found and are listed in Table 2. The first three target words have single cues with a low probability of retrieval but dual cues with a high probability

³ Fragment theory, when modified to be based on stochastic independence, can be shown to follow the $p(T | X \text{ and } Y) \leq p(T | X) + p(T | Y)$ inequality. If the two terms on the right of the inequality are subtracted from both sides, then the inequality takes the form $p(T | X \text{ and } Y) - p(T | X) - p(T | Y) \leq 0$. Equation 8 provides terms for $p(T | X \text{ and } Y)$. According to fragment theory, $p(T | X) = p(T-X) + p(T-X-Y) - [p(T-X) * p(T-X-Y)]$, that is, the probability of retrieving T, given X, equals the probability of the presence in memory of each of the two fragments that could lead to T's being retrieved, given X, less a term to ensure that the same retrieval is not counted twice if both fragments are in memory. Similarly, $p(T | Y) = p(T-Y) + p(T-X-Y) - [p(T-Y) * p(T-X-Y)]$. Substituting these terms the $p(T | X \text{ and } Y) - p(T | X) - p(T | Y)$ and collecting terms yields: $-p(T-X-Y) - [p(T-X) * p(T-Y)] * [1 - p(T-X-Y)]$. Because all the probabilities and the term $[1 - p(T-X-Y)]$ must be positive or zero, the whole expression must be less than or equal to zero as required by the inequality.

Table 2
Probability of Giving Selected Target Words in Experiment 1

Target	Cues		Single cue		Dual cue
	Rhyme	Meaning	Rhyme	Meaning	
Ghost	ost	A mythical being	.00	.00	1.00
Steel	eel	A building material	.00	.04	1.00
Year	ear	A unit of time	.04	.00	1.00
Average			.01	.01	1.00
Cat	at	A 4-footed animal	.22	.12	.82
Dog	og	A 4-footed animal	.18	.62	.36
Sad	ad	An emotion	.24	.00	.80
Average			.21	.25	.66

of retrieval. The last three target words have a higher single-cue but lower dual-cue probability of retrieval than do the first three words. As is apparent from the values in Table 2, it was difficult to find target words that had low probabilities of cuing in the dual-cue condition.

The data in Table 2 are evidence against any single monotonic composite model. One set of single cues has a very low cuing probability of approximately .01 and a very high dual cuing probability of 1.00, whereas another set has a moderate single cuing probability of about .23 and a moderate dual cue probability of .66.

There is, however, a statistical flaw in the demonstration. Choosing extremes can combine true effects with those of random variations. That is, in a replication there may be regression to the mean large enough to remove any observed differences. Experiment 3 addresses this concern.

Method

Cues for the six target words shown in Table 2 were presented to the subjects by using typed booklets. In order to avoid ambiguity in pronunciation that might accompany written as opposed to oral presentation, rhyme cues were given by a rhyming word instead of a rhyme ending. The rhyme cues were the lowest probability rhyme word that had a frequency greater than one in the McEvoy and Nelson (1980) norms. Where more than one word existed at a given probability, the first word listed was used. In this way, bizarre rhyme cues were avoided, and popular responses were not excluded from being given by the subjects.

A between-subjects design was used with 90 subjects in each of three conditions. Subjects in the rhyme, the category, and the dual-cue conditions were asked to record one word that fit each of their six respective cues as given in Table 3.

Results

The minimum number of valid responses for any word in any condition was slightly over 70. In order to provide the same amount of data for each word and condition, subjects' responses were scored until 70 valid responses were obtained for each target word in each condition. The results shown in Table 3 follow those of Table 2. The nonmonotonic relation again argues against any single model based on the independent combination of single cue probabilities.

Discussion

Only six target words were used. Technically, that is not a flaw because only two target words are needed to argue that a single monotonic composite model is inadequate. However, the argument would be made much stronger by showing that the stimuli in Tables 2 and 3 differ in a clear, easy-to-understand way that makes the production of more examples possible. Although the stimuli in Tables 2 and 3 were selected to exhibit just the property necessary for the demonstration, they are not just random pairs of cues that violate a model, but rather cues that share interpretable properties. The first

Table 3
Probability of Giving Selected Target Words in Experiment 3

Target	Cues		Single cue		Dual cue
	Rhyme	Meaning	Rhyme	Meaning	
Ghost	post	A mythical being	.16	.01	1.00
Steel	deal	A building material	.00	.00	1.00
Year	gear	A unit of time	.03	.00	1.00
Average			.06	.00	1.00
Cat	spat	A 4-footed animal	.27	.14	.78
Dog	clog	A 4-footed animal	.38	.56	.77
Sad	add	An emotion	.23	.06	.67
Average			.29	.25	.74

three targets each have two single cues with low cuing probabilities. These single cues, when combined, limit the choice of a response to one word in the whole English language (or at least to only one word that the subjects know). The second three targets each have two single cues with moderate cuing probabilities. In contrast to the first three targets, these single cues, when combined, still allow a choice of responses to the dual cue (e.g., *cat, rat; dog, frog, hog; sad, mad, glad*).

To generate more stimuli like the first three targets, one has to find words that are the only words that fit into two categories and that are low-dominance responses to those categories. For rhyme and meaning, a search of the first five categories from Battig and Montague suggested the following target from each category: *quartz, epoch, mom, furlong, and antimony*. Almost every category examined by Battig and Montague had at least one low-dominance word that did not rhyme with any other word in the category, so these words are not hard to find. To generate more stimuli like the second three targets, one has to find words that are one of many words that fit into two categories and that are moderate dominance responses to those categories. Such words are more difficult to find. For rhyme and meaning, one word from each of the following sets might do: *baseball, basketball, football, racquetball; rayon, orlon, nylon, dacron; nitrogen, oxygen, hydrogen; mother, father, brother, sister; strawberry, raspberry, blueberry; September, October, November, December*.

General Discussion

This article investigated how properties of stimuli combine to predict behavior. A review of existing literature showed that when *single* cues uniquely identify their target, a composite model—fragment theory—predicts the effect of a dual cue from the strength of its single cue components. However, when single cues do not uniquely determine their target, the dual cue often greatly reduces the number of possible targets. In this case, neither fragment theory nor any other composite model can account for the data. In more general terms, theories that predict behavior solely on the basis of individual feature strength can be shown to be adequate under some conditions but not under others. For retrieval, the presence or lack of a unique cue to target relation has been identified as a way to decide, a priori, whether behavior can be predicted from independent feature strength.

The results of cuing words with their rhyme and meaning categories can be summarized in terms of the Venn diagrams of Figure 1. The top panel of Figure 1 shows what is true of approximately 97% of the arbitrarily selected rhyme and meaning categories on the basis of analysis of the set size data from existing norms. There is no word in one category that fits into the other category. The second panel of Figure 1 shows what is true for over 2% of arbitrarily selected rhyme and meaning categories on the basis of set size analyses of both Experiment 1 and the existing norms. There is only one word that belongs to both categories. The third panel of Figure 1 shows what is true of less than 1% of arbitrarily selected rhyme and meaning categories on the basis of set size analyses of both Experiment 1 and the existing norms. For all three cases, the strength or prototypicality of the words in each

category is of little relevance to their likelihood of being given as a member of both categories. Rather, it is the extent to which the two cues when combined limit the choice of possible responses. The requirement that each single cue (and therefore the dual cues) uniquely defines its target removes this constraining effect and allows other effects to be noted.

Viewed in this light, the results of the present study resolve a paradox. Rhyme is not an especially good cue for recall in laboratory research (Craik & Lockhart, 1972; cf. Morris, Bransford, & Franks, 1977; Nelson & McEvoy, 1979; and Nelson, Wheeler, Borden, & Brooks, 1974), yet it is among the most used mnemonic aids outside the laboratory and in oral traditions. The lack of generalization of laboratory results occurs because care is taken in laboratory experiments to ensure that rhyme and other sound and orthographic properties do not interact with meaning cues to limit possible responses in the way in which rhyme does in most real-world situations. Rhyme is an effective aid to recall in the laboratory when it limits alternatives (Bower & Bolton, 1969; Solso & Biersdorff, 1975), and it almost always does this in the real world. Laboratory results generalize to nonlaboratory situations when properly applied (Landauer, in press).

The arguments made here are about how two cues act together to limit possible responses. As Nelson (personal communication, September, 1988) noted, there is an analogy to be drawn to models of memory that are based on two or more processes acting together. Theorists must be cautious about assuming that such processes act independently, especially where the processes could limit responses when combined.

The results of the present study also shed light on some issues raised by the study of oral traditions. Poetics, which is widely used in oral traditions, acts together with meaning constraints to limit choices and thereby lighten the memory load. Once a singer has a "running start" on a song, words will be easier to recall because there are so few words that will be suitable. Pieces can be stable over many tellings without having their exact words fixed because the possible word choices that follow both the poetic and meaning rules of the genre are limited. Thus *bay* may change to *gray* and back again over many tellings in lines such as "She rode a dappled bay . . . one hour before day" without ever changing to a quarter horse (Wallace & Rubin, 1988a, 1988b). In addition, some words may remain fixed because a likely alternative does not exist. With respect to the particular findings of this article, rhyme could be a major poetic device in many English genres because of the way in which it constrains choices. These speculations are hypotheses that we are pursuing by using oral traditions.

If multiple constraints are prevalent in oral traditions and if they are as powerful as the present study indicates they are, recall in oral traditions may involve much less of a thought process and much more of a pattern-recognition or constraint-satisfying device. Instead of analyzing a situation and deciding upon the best alternatives, singers need only recognize a situation and respond appropriately. In many retrieval situations we may do the same. This is the same conclusion that Chase and Simon (1973) suggested for expert chess players, that Norman (1988) suggested for most everyday expertise,

and that McClelland, Rumelhart, and Hinton (1986) suggested for almost everything.

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