Memory & Cognition
1993, 21 (2), 193-197

Short-term memory: A brief commentary

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Over the years, a metatheoretical view of short-term memory has developed. This view, closely related to the "modal" model from the 1960s, is supported by an increasing base of neurophysiological data, and a wide variety of empirical findings. It treats short-term memory as (1) the temporary, above threshold, activation of neural structures (related in not-too-well-specified ways to various recency effects); (2) a work space for carrying out virtually all cognitive operations involved in human cognition; and (3) the source of capacity limitations, accounting for certain memory limitations and most attentional limitations. The main problem with this view is the fact that it encompasses virtually everything that we are concerned with in human cognition—a *successful* model would almost be a general model of cognition, something the field has not yet approached. This situation is not grounds for despair. Progress is being made on many fronts, notwithstanding the fact that the most successful models are focused on specific task domains. Recent advances include an increasing awareness of the necessity for detailed models of short-term retrieval, a theme reflected in a number of articles in the present collection.

As a commentator on the presentations in the Psychonomic Society symposium, from which the present collection of articles grew, I have decided to limit my remarks to some very general themes: I will attempt to place the present state of research and theory concerning short-term memory in some larger perspective (specifically excluding attacks upon and defenses of particular models and approaches).

A few years ago I was taken aback when a colleague asked me, "Whatever happened to short-term memory? Didn't people used to study that?" Upon reflection, the question seemed less surprising: The field had expanded and fragmented to the point that the general term *short-term memory*, or any of its variants, no longer transmitted information precise enough to be useful. What had happened was that the simplified early models in the field were superseded by a generally accepted metatheoretical framework, in which short-term memory became virtually synonymous with cognition in general. The expansion of the scope of the general concept coincided with two other trends: (1) the scope of models aimed specifically at short-term memory per se tended to narrow, often restricted to particular experimental paradigms; and (2) almost every domain of cognition incorporated some model of short-term memory. We have seen short-term memory components in most neural net models, and in models of language processing, reading, problem solving, individual differences, developmental changes in cognition, decision making, motor learning and performance, memory and learning in general, attention and search, neurophysiological data, clinical abnormalities of cognition, and many more. Of course, these applications have tended not to incorporate complete models of short-term memory, and, although they usually share a common perspective, have not been identical in detail. Some would regard the present state of affairs as a cause for despair; I regard it as a natural evolution of a field that, in many respects, is still in its infancy.

As a place to begin, let us try to identify a currently shared conception of short-term memory. It appears that there are three widely accepted dimensions of the concept, which also held for the modal model of the 1960s (e.g., Atkinson & Shiffrin, 1968).

1. Short-term memory is related to the temporary activation of neural structures above a resting or baseline level (including patterns of synchronous firings). This very old view reappears in the present set of articles in various guises (including Baddeley & Hitch, 1993, in their "cooling light bulb" analogy), and is supported by a wide array of neurophysiological evidence (see, e.g., Schneider, 1993). Technology now permits us to watch patterns of enhanced activation appear in local brain structures, and move over time in response to tasks and instructions. Direct links between such activation patterns and behavioral measures of short-term operations in humans have, until recently, been studied by ERP recordings with scalp electrodes (finely tuned in time, but less precise as to brain location), but now are beginning to be studied with such techniques as magnetic resonance. There seems to be little doubt that these short-term activation patterns contribute to changes in synaptic connectivity over time. The synaptic changes hold long-term memory during periods when local activation may be at resting level. The

A version of this article was presented as a commentary as part of a symposium entitled "Short-term memory: Where do we stand?" at the annual convention of the Psychonomic Society in San Francisco, November 1991. The work was supported by NIH Grant 12717 and AFOSR Grant 870089. Requests for reprints should be addressed to the author at Department of Psychology, Indiana University, Bloomington, IN 47405.

activation patterns themselves are assumed to be related to what we mean by short-term memory (though detailed models of the linkage between the two are not too prevalent, and generally quite new, most often appearing in neural net modeling). It may well be the case that this dual view of activation and permanent synaptic changes is too simple, with temporary chemical changes acting as another short-term stage on the route to final consolidation, but ties between such stages and human short-term memory behavior are even more tenuous than those between activation and behavior. It should also be pointed out that the activation assumption allows for many varieties of short-term memory: Rates of loss, causes of interference, and other mechanisms need not be identical for all types and locales of activated information.

It is essential to note that activity alone does not guarantee retrieval from short-term memory. One cannot simply assume that the contents of short-term memory may be dumped into some sort of output process. A model of retrieval from short-term memory is also needed (as seen, for example, in the present articles by Schneider, and Schweikert, 1993, and as discussed here by Baddeley & Hitch). I will return to this point below.

As far as retention goes, the idea is that the decay of activation puts limits on short-term retrieval. No end of confusion over the years has resulted from the fact that, according to dual-store models, *performance* must always be a joint function of short-term and long-term retrievals (except for certain kinds of tasks in certain clinical cases, such as the case of H.M.). This fact tends to produce positively correlated predictions for paradigms that are typically classified as short term or long term. There are other reasons, as well, to expect data from short- or long-term retrieval situations to show similar patterns. For one thing, if short-term activation is the cause of long-term learning, certain patterns of similarity will be inevitable (see Cowan, 1993, this issue). Also, there is likely a correlation between retrieval from the two systems, due to common underlying variables (like coding or rehearsal strength, or common retrieval cues). Finally, similar data might be produced for quite different reasons. For example, recency effects could appear in short-term retrieval for reasons related to decay of activation, and could appear in long-term retrieval due to the use of probe cues, including context, that tend to diverge increasingly from the stored images as time passes. (Although it may be possible to argue that changes in short-term retrieval also depend on context change, it seems likely that such models would need to assume at least two processes or two rates of change; see Glenberg et al., 1980.)

These considerations notwithstanding, the existence of similar retention patterns in certain short-term and long-term retention situations has led some researchers to question the need for separate systems (see, e.g., Baddeley & Hitch, 1993; Crowder, 1993, in the present collection). The one-store view has not achieved wide acceptance, nor has it generally been worked out in detail. I suspect that a one-store model capable of carrying out all the functions currently ascribed to dual-store systems, and capable of handling the wide array of data from differing types of paradigms, would end up with enough subsystems and sufficient complexity that the *one-store* description would be inappropriate. This is not to say that dual-store systems easily handle all the existing data. Models of short-term retention have been a bone of contention in the literature for as long as the field has existed, and are constantly undergoing refinement. The present collection of articles provides a case in point.

Nevertheless, the researchers questioning the dual-store approach have a valid concern: If both long-term and short-term retrievals can exhibit recency, what are the implications of *temporary* activation? Theoretically, there are large differences, one of which relates to the theoretical permanence of loss. Once activation decays, short-term retrieval is not theoretically possible at any later moment. In contrast, it is generally assumed that long-term memory is extremely long lasting (and virtually unlimited in capacity). The failures of retrieval from long-term memory are related to choice and use of cues. Thus, long-term retrieval may fail at one moment and succeed at a later moment. In theory, short-term retrieval depends on cues, but in typical studies the cues are quite specific and useful (such as a pointer to a position in a display that contained a character a fraction of a second earlier). Although a poor cue might induce a retrieval failure from short-term memory, decay of activation would tend to make later short-term retrieval unlikely, even if a better cue was provided after a delay. In contrast, there is a long-lasting potential for long-term retrieval after an earlier failure.

In practice, it is most difficult to find experimental realizations of this theoretical difference, and the same is true of most other single criteria for short-term/long-term differences. In my opinion, I doubt that it will be possible to come to a decision between one- and two-store systems as a basis for retention data using a few key results, logical considerations, or high-level, abstract thinking. Instead, I think it will be necessary to compare well-worked-out formal systems of each type, with each applied to many types of data.

2. In 1968, Dick Atkinson and I chose to focus upon control of cognition as a fundamental characteristic of human short-term memory. This theme appears, for example, in Schneider's article. The idea is that operations are carried out within the short-term system and are bound by the system's limitations. Such operations are virtually universal, including all attentional and intentional operations, and perhaps some automatic operations as well. Examples of such control processes include where to direct peripheral attention, how to rehearse current information, how to code new inputs, how to choose cues to retrieve from short- and long-term memory, controlling and comprehending language, thinking, planning of production (e.g., for speech and language), managing motor control, and decisions of all sorts, to name just a few. This idea has appeared again and again with other terminology (e.g.,

working memory, blackboard, etc.). This concept is also intimately related to the set of data and proposals known as *levels of processing* (Craik & Lockhart, 1972), the general idea being that the type of coding determines the efficiency of later retrieval (usually from long-term memory).

The problem with this view, again, is its universality—all intentional cognition resides in short-term memory. Is there room in the short-term system for all the necessary information and machinery? Much of the machinery is likely automatic, not using short-term capacity (see Point 3, below). A few theorists have included both content and a few relevant operations when calculating the capacity of short-term memory, and some neural net models have begun to incorporate operations within short-term memory (e.g., Schneider), but the issue remains largely unaddressed.

It cannot be denied that the operations within short-term memory affect theoretical interpretations of data. As an example, consider the results in Baddeley and Hitch: A concurrent task in one modality may spare recency for a list of words presented in another modality, but depresses the recall of older words in that list. Maintenance of the words in the input list in an active state is only one of the operations that must be carried out in short-term memory. Others include control of the entire cognitive system and coding of the inputs into a form that will facilitate long-term retrieval. The subject may be able to choose which operations to sacrifice in order to carry out a concurrent task. In particular, short-term maintenance may be retained at the expense of coding operations, reducing retrieval from long-term memory.

3. It is generally accepted that short-term memory has a limited capacity, and that the need to carry out operations with a limited capacity system provides the fundamental basis for the use of attentional processes. In 1976, I wrote a chapter espousing the view that capacity limitations are a fundamental characteristic of short-term memory. The range of limitations and their operation span the fields of attention and cognition. Great debate over the years has centered on issues such as the placement of limited capacity in the system (e.g., an early peripheral bottleneck?), the number of limitations of a given type, the number of types of limitations, and the separate existence of automatic processes that allow limitations to be bypassed or overcome.

One should not be misled, however, into identifying short-term memory with attentional focus. Years of research on attentional effects (e.g., Shiffrin, 1988), and short-term research (such as that discussed here by Cowan) make it clear that attentional focus cannot be identified with the entire set of currently activated information, but represents a far smaller subset instead.

Content capacity refers to the idea that there is a relatively fixed limit on the number of items of a given type that can be held without error in short-term memory (and to other similar limitations). The present articles by Cowan and Schweikert present models that produce behavior of this sort, and work quite well indeed within a limited set of experimental paradigms using restricted types of materials to be remembered. However, as mentioned above, there has been great debate concerning the mechanisms of short-term forgetting, including that concerning separate forgetting mechanisms for short- and long-term systems, and the number of short-term systems. I will return to this point below.

In summary, there is presently a rather nonspecific *modal* view of short-term memory. This view contains three components: *temporary activation*, *control processes*, and *capacity limitations*. These three components are certainly not orthogonal, and certainly not synonymous. The precise relationship between them (even among those accepting the framework) remains an area of active study (e.g., to what degree is the temporary nature of the memory due to a particular capacity limitation?). Despite general acceptance, it is probably fair to say that this modal view needs a great deal of work before it can be described as a model or a theory. A few well-worked-out models, roughly consistent with the framework, do a good job of predicting the data from particular paradigms (e.g., the continuous-memory paradigms discussed in Atkinson & Shiffrin, 1968, the serial recall of short lists discussed by both Cowan and Schweikert, in the present collection of articles, and the perturbation model worked on by Estes, Lee, Healy, and others; see Lee, 1992, for one review), but a generally applicable model remains a goal for the future.

Kinds of Short-Term Memory

In 1968, Atkinson and I partitioned short-term memories into sensory registers and an auditory-verbal-linguistic component. Research over the years since then suggests that this view was misleadingly simple. The rules governing short-term residence can be examined for every kind and level of information that can produce activation. It seems clear now, on logical grounds as well as the weight of evidence, that short-term memory is the accumulation of all of these. The degree to which the rules governing residence, rehearsal, coding, attention, and so forth, differ for all these is far from clear. However, some differences are clearly identifiable. For example, researchers have proposed and collected evidence for a phonological buffer and/or articulatory loop (e.g., Baddeley, 1986) with residence times near 2 sec. However, there are numerous other forms of short-term memory, with both Martin (1993) and Potter (1993) arguing that other short-term memories (e.g., involving routes from visual inputs to conceptual and language forms) are far more important for normal human functioning. Even these short-term forms do not come close to exhausting the possibilities for which evidence has been collected, including various sensory systems (such as those we described in 1968, by sensory registers), with residence times in the hundreds of milliseconds, visual-spatial sketchpads, veridical-visual versus abstract-visual codes (e.g., Posner, 1969), and others. The kinds of information stored may depend on

the task, the subjects, the instructions, and the subjects' intentions (e.g., store inputs for implicit or explicit tests), and may be used differentially depending on the test at retrieval (e.g., stem completion vs. serial recall).

It must also be obvious that information is transformed from one type to another during encoding. The properties of these different levels may be quite different. An obvious example is the transfer of words presented visually into a phonologic/linguistic form. The encoding stages, which may occur very rapidly, could reach conceptual levels that are quite deep, as discussed by Martin and Potter in this issue.

Another point that has come to be increasingly appreciated since the 1960s is the necessity for attributing structure to short-term memory, rather than treating it as an undifferentiated decaying mass (e.g., Cowan). This point goes hand in hand with the notion of different types of short-term activation, and is consistent with the view that retrieval from short-term memory must be a cue-dependent process, incorporating mechanisms for translating recovered information into responses (see Schweikert), and containing its own set of rules for failing and succeeding.

Retrieval From Short-Term Memory

If the contents of short-term memory comprise all of activated memory, including the ever-changing flood of sensory inputs, the transformations and encodings of those inputs, the internally generated plans and thoughts, and the products of operations carried out within short-term memory, then it is clear that only a small portion of this information can be the focus of attention at any one time, and retrieval of only a tiny fraction of this information will generally be possible. For information that is currently sufficiently active and complete, an appropriate retrieval operation (i.e., the right set and type of cues) may well produce accurate retrieval. For example, after a brief display of letters, a cue for one or a few positions might produce an accurate report if the cue delay is short enough (e.g., Sperling, 1960). For types of information not tied to sensory systems, it is less clear what the optimal cues would be. On the other hand, information is assumed to decay from short-term memory; after some decay has taken place, a partial and inaccurate trace may be left. In such a case, even with optimal cuing, the information recovered may be insufficient to allow perfectly accurate retrieval. In such cases, a model of recovery (or reconstruction, or whatever term is most descriptive) is essential. One approach to this problem is proposed by Schweikert. In a somewhat different setting, another promising approach to retrieval dynamics is seen in work by Dosher and her colleagues (e.g., McElree & Dosher, 1989). In comparison with models of long-term retrieval, however, such models for short-term retrieval are still at an early stage of development.

The Nature of Short-Term Forgetting

This topic is perhaps of the greatest interest, is the subject of the greatest amount of research, and is the most controversial. The nature of some of the current research, and some of the questions that are being asked, are well represented by the present collection of articles. We have excellent accounts of the data from certain limited experimental paradigms, such as serial recall of short lists (see Cowan and Schweikert), but are a long way from a generally applicable theory. Although it is tempting to extend these brief comments by engaging in a critical evaluation of the current status of theories of short-term forgetting (particularly including the present articles), I will not do so lest this brief overview turn into a book-length treatise.

Varieties of Models

The concept of short-term memory has virtually become a universal feature in theories of cognition. This concept usually contains components of temporary activation, control of cognitive operations, and limited capacity. However, such a concept is too general and too vague to be described as a theory or model. Attempts to produce a general theory with these components have, at least until recently, proceeded little beyond the models of the 1960s (see the present article by Schneider for an attempt to move in this direction within a neural net framework). At the other extreme we have seen important advances in our understanding of, and modeling of, certain specific short-term memory tasks, such as memory and visual search (e.g., McElree & Dosher, 1989), and short-term serial recall (e.g., the present articles by Cowan and Schweikert). Somewhere between these two extremes, but closer to the general framework, are models couched in terms of metaphors and analogies (see, e.g., the present articles by Baddeley & Hitch and Crowder). Such models may be imprecise (to say the least), but nonetheless play an important role in generating new hypotheses and new experimental tests.

Assessment

Research into short-term memory has not faded away, but rather has become part and parcel of the general study of cognition. The simplicity of approach of some of the early models has been lost in the light of recent experimental findings, but slight variants of those models still provide a useful enough approximation so that they have achieved general usage. Experts who study short-term memory itself have certainly gained an appreciation of its complexity and its global and fundamental role in cognition. What is perhaps most clear is the fact that many critical advances are still to take place.

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(Manuscript received June 17, 1992;
revision accepted for publication August 20, 1992.)