WORKING MEMORY, COMPREHENSION, AND AGING: A REVIEW AND A NEW VIEW

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I. Introduction

A reasonable case can be made for the view that linguistic competence remains invariant across the adult life span (Light, 1988). Contrast this conclusion with one derived from the literature on aging and memory: Here age deficits of varying sizes are common (see Craik, 1983; Kausler, 1982). This is important to our general concern with discourse comprehension because there is every reason to believe that linguistic performance is constrained by memory functioning (Clark & Clark, 1977; Just & Carpenter, 1987). Consider, for example, the performance of younger and older adults on two different tasks tapping knowledge of word meanings (Bowles & Poon, 1985). Younger and older adults did not differ on a task which required them to determine if each of a series of letter strings was a word. However, older adults showed poorer performance (as measured by accuracy and speed) on a task which required them to produce target words when cued with their definitions. The important difference between the two tasks appears to be the greater retrieval demands made by the definition task. These results fit well with the contention that memory factors are important determinants of the degree of age differences in linguistic performance.

Indeed, even the overarching objective of linguistic competence, comprehension, is constrained by performance circumstances that may well be memory based: understanding and remembering are substantially impaired for older adults as compared to younger adults when a message is presented rapidly rather than slowly (e.g., Stine, Wingfield, & Poon, 1986) or when it contains syntactic structures that put heavy as compared to light demands on working memory (e.g., left-branching clauses vs. right-branching clauses; Kemper, 1988).

We begin this article with an overview of the theoretical and empirical literatures that address aging and discourse comprehension. We then present a series of five studies which were guided by a particular working memory viewpoint regarding the formation of inferences during discourse processing. The data, although in broad agreement with our initial framework, suggested that an altered viewpoint might be more useful in guiding further research. In the next section we turn to a critique of working memory models and of the broader category of limited capacity models that they exemplify. Our data, together with these criticims, lead us to propose, in the final section, a new framework for conceptualizing working memory, one that draws on ideas from current parallel-architecture attention theories, from social cognition, from classic interference theory of forgetting, from work on reading and discourse comprehension, and from cognitive gerontology. It is a framework developed from our interest in normal aging and from our assessment that breakdowns in cognition, as occur with aging (and possibly with depression, chronic high arousal, and chronic illness), may prove to be as valuable a window into normal cognitive functioning as breakdowns in amnesia and aphasia are currently proving to be (e.g., Squire, 1987).

II. The Theoretical Framework: From General Capacity to Working Memory

The research reported here is part of an evolving understanding of the relations among aging, memory, and discourse processing. We began research on this topic using a "general capacity" view, which was modified from an earlier perspective (Hasher & Zacks, 1979, 1984) to be appropriate for discourse processing in general and inference generation in particular. Two central assumptions characterize most general capacity models: (1) cognitive functioning is constrained by the resources that are momentarily available, and (2) the multiple components assumed to occur in almost every task vary in the resources that each needs for maximal performance (e.g., Hasher & Zacks, 1979, 1984). This general framework was then extended to develop an understanding of the cognitive deficits associated with aging. As applied to adult age differences in cognitive functioning, a third central assumption is that capacity declines across the adult lifespan.

Taken together, these three capacity assumptions predict that the degree of age-related decline on a particular task will depend on the resources of the individuals involved and, critically, on the demands made by the subcomponents of that task. When those demands are minimal (as when most of the processing is nearly automatic), age deficits too should be minimal. Age deficits, however, should increase as the cognitive demands of task components increase. Such a view is consistent with that of Craik and collaborators (1983; Craik & Byrd, 1982; Craik & Rabinowitz, 1984) who postulated an age-related decline in the "processing resources" available for capacity-demanding cognitive operations. This deficit reduces, at both encoding and retrieval, the kinds of self-initiated activities that result (1) in the generation of elaborated and distinctive memory traces and (2) in subsequent access to those traces, at least under circumstances of limited environmental support (or cues) to guide retrieval.

Such viewpoints provide a useful heuristic for integrating a considerable research literature (see Craik, 1983). For example, we have reported some age differences in memory for frequency of occurrence (Hasher & Zacks, 1979) which disappear when subjects are tested using a task that provides considerable contextual support for retrieval (Attig & Hasher, 1980). Even the often reported age deficit in memory for particular items, found in tasks such as keeping track of the elements in a series (Zacks, 1982), free recall, and list learning (see Craik, 1983; Kausler, 1982, for reviews), can be eliminated when testing provides substantial contextual support for retrieval (Light & Singh, 1987). In the Light and Singh work, perceptual identification and word completion of previously presented words was compared to the identification and completion of new words in an implicit memory task. On these two memory measures, age differences were small and unreliable, a result which can be attributed to the strong contextual support for memory trace access that these two tasks provide (see Jacoby, 1983; but see also Light & Singh, 1987).

Discourse comprehension is an ideal domain for assessing limited capacity frameworks because most models of discourse processing assume that multiple components, demanding substantially different levels of cognitive resources (e.g., LaBerge & Samuels, 1974; Perfetti, 1985), are involved. Thus, for example, access to a lexical representation from either a visual array or an auditory message is virtually capacity free. Other components, such as inference generation, may vary from being extremely undemanding (as in inferring that a gun was used in a shooting incident) to extremely demanding.

A. Discourse Processing and Working Memory

In the discourse processing literature, the notions of limited capacity and of differential demands on that capacity by component tasks are most often embedded in the concept of working memory. Working memory, in turn, is conceived of as playing a central role in discourse comprehension. It bears the burden of orchestrating and enabling the multiple processes that co-occur to make skilled comprehension possible (Daneman & Green, 1986; Just & Carpenter, 1987; LaBerge & Samuels, 1974; Sanford & Garrod, 1981; Stanovich & West, 1983). In most of this research (although see Baddeley, 1986),[1] working memory is conceived of as a limited capacity mechanism which shares its resources between a storage function (as when it holds an earlier phrase, clause, or larger unit) and a set of processing functions (as when it analyzes syntax, establishes local meanings, and integrates meanings across psychological units).

Demanding inferences may be seen as placing a large burden on the storage function of working memory, requiring it to serve two types of information: (1) that presented in preceding portions of a message and (2) any prior knowledge activated by the message.[2] There is no doubt that having prior information accessible in working memory is critical for comprehension to flow smoothly. The research of Glanzer and collaborators (Fischer & Glanzer, 1986; Glanzer & Nolan, 1986) shows clearly that having access to the information from the one or two immediately preceding sentences enables reading to proceed apace. Even a brief interruption will disturb this process, presumably by displacing relevant, antecedent information from working memory and substituting it with something less relevant to the ongoing message. If, however, the amount of capacity allocated to higher-level processing components, such as establishing connections among elements of a text, leaves little for the support of necessary information in active storage, these processes can be expected to malfunction, preventing inferences from being drawn and preventing the establishment of a coherent and integrated representation.

Because of the intuitive and logical appeal of this conception as well as the introduction of a measure of working memory that seemed to be a powerful individual difference variable (Daneman & Carpenter, 1980, 1983), the notion of working memory has both guided considerable re-

[1]Baddeley's research (see Baddeley, 1986) has focused not on the central executive of working memory, to which this description applies, but on three subsidiary components of working memory: the articulatory loop, the phonological store, and the visual spatial scratch pad. Thus, although the concept of working memory as used in some areas of the discourse-processing field originated with the Baddeley and Hitch (1974) notion, developments in discourse comprehension have not necessarily followed Baddeley's lead in the subsequent development of this concept.

[2]In most current work, the phrase "prior knowledge" refers to *text-relevant* information. As will be seen, other types of stored information are important for comprehension and memory as well.

search in the 1980s and been widely used as an explanatory concept. This has certainly been true in cognitive gerontology where the notion that working memory capacity declines with age has been especially compelling.

Our application of a working memory capacity model to aging and discourse comprehension hinges on one assumption beyond those already articulated for a general capacity view: in the competition for a decreasing supply of capacity, the processing component of working memory has higher priority than does the storage component (Spilich, 1983; cf. Light & Anderson, 1983). This latter argument stands on a 2-fold rationale: (1) the initial phases of linguistic processing are probably largely stimulus driven (consider, for example, lexical access), and (2) social convention requires that a listener take turns and/or nod or verbalize agreement at appropriate points in the transmission of a message. To do this, ongoing processing of words, phrases, and larger units must occur.

Of direct relevance to the assumption that the storage function of working memory is differentially reduced with aging is evidence suggesting that variables that make demands on the storage component have a particularly disruptive effect on older as compared to younger adults. For example, Light and Capps (1986) have shown that the ability of younger and older adults to determine the antecedent of a pronoun is a function of how much information intervenes between the antecedent and its subsequent pronoun (see also Cohen & Faulkner, 1984; Wright, 1981). If the noun–pronoun relationship occurs in contiguous sentences, older and younger adults are equally able to determine the antecedent. If the relationship is separated by intervening sentences, older adults are substantially disadvantaged. These studies (and others, see Light & Albertson, 1988) suggest that when the demands on storage are high, older adults are particularly disadvantaged compared to younger adults.

There is one possible exception to the pattern of evidence consistent with an age-related loss of storage capacity in working memory: adults with high verbal ability and/or levels of education seem to be buffered from the considerable aging declines often found in discourse comprehension tasks (e.g., Hultsch & Dixon, 1984; Hultsch, Hertzog, & Dixon, 1984; Zelinski & Gilewski, 1988). We and others (Cohen, 1988; Hunt, 1985; Perfetti, 1985; Zacks, Hasher, Doren, Hamm, & Attig, 1987) have suggested that adults with high verbal ability may use more efficient processing strategies than adults with lower ability, thereby enabling at least some sparing of functioning, including sparing of the storage component in working memory. Some suggestions in the individual difference literature support such a view (see Carpenter & Just, 1988), with correlations between working memory span and vocabulary generally ranging from approximately .35 (Zacks & Hasher, unpublished data; Hartley, 1986, 1988) to approximately .50 (Daneman & Green, 1986; but see Baddeley, Logie, Nimmo-Smith, & Brereton, 1985, for an exception).[3]

B. Working Memory and Inferences

Thus, a working memory capacity view has some validity for integrating existing research on aging and discourse comprehension and memory. The research reported in this section attempts to apply this view to the ability to create and remember inferences. Inferences are critical to the establishment of a coherent and integrated representation of a text, without which comprehension is poor and retrieval extremely impaired (Bransford, 1979; Bransford & Johnson, 1972). The establishment of an integrated representation requires that a listener or reader produce at least *some* of the anaphoric and causal connections that are implicit in a text (e.g., Clark, 1977; Sanford & Garrod, 1981; O'Brien & Myers, 1987).[4] In turn, inferences vary in the demands they place on working memory capacity. Some require the integration of two familiar pieces of information (e.g., that the vase on the dinner table was the container for the roses that were being admired by the guests). Some inferences require only the integration of a well-learned fact with the incoming information (e.g., the sentence "He shot her" implies that a gun was used). Such inferences should create relatively few problems, even for those who have reduced working memory capacity, because they require so little storage. Indeed there is evidence that older adults are not particularly disadvantaged in the formation of such inferences (see Belmore, 1981). By contrast, other inferences require the maintenance of substantial information in working memory, often from different segments of a message, and sometimes from general knowledge as well, in order for processing to establish the logical or pragmatic connections among the relevant aspects of information.

Inferences that place high demands on storage capacity would be expected to show substantial age differences—and they do, as will be shortly seen (see also, e.g., Cohen, 1979; Light & Albertson, 1988; Light & Capps, 1986; Light, Zelinski, & Moore, 1982). That research reveals that older adults have problems *forming* even critically important inferences, at least under some circumstances. A central limitation to the formation of in-

[3]For a measure of working memory capacity, see Daneman and Carpenter (1980, 1983) and Daneman and Green (1986).

[4]There is increasing evidence that even young adults do not spontaneously form all of the connecting inferences that a text permits (see Alba & Hasher, 1983; McKoon & Ratcliff, 1986). Some inferences may be more critical for text cohesion than others. Current evidence suggests that anaphoric (pronoun to referent) and causal–sequential inferences are among those that are drawn on line (see O'Brien & Myers, 1987). As will be seen, our research relies on inferences that are critical to a logical understanding of a paragraph.

ferences during on-line comprehension appears to be the inability of older adults to retrieve quickly and efficiently the antecedent information necessary to form an inference. This insight led us to address the question of what factors might function to limit on-line retrieval; it also led to an answer, proposed in the final section of this article, with broad implications for discourse comprehension and memory across the lifespan.

III. The Empirical Evidence: Aging, Inference Formation, and Retrieval Problems

The three experiments we report first represent tests of the notion that reductions in the storage capacity of working memory explain most of the age-related reductions in inference formation. Two other experiments addressed the role of retrieval problems in inference formation.

A. Inference Difficulty Studies: Experiments 1–3

The materials for these studies were 12 paragraph-length passages (borrowed from Alba, 1984) designed to vary the storage demands on working memory for encoding an inference about a central target event. For example, central to a correct understanding of the passage entitled "The Artist" (see Table I) is the recognition that a phone call the protagonist

TABLE I

An Example of Materials Used in the Research

The Artist

Explicit and Expected versions (in the latter, the phrase in parentheses is omitted)

The artist was busily painting one day when he received the phone call he had been expecting from his doctor's office. He was concerned about the results of a series of lab tests he had taken. The artist was told he had three more months (to live). He was shocked to hear this kind of news from his doctor. Although he had not been feeling well, he still had not expected to hear such bad news. His doctor expressed sympathy and hung up. Suddenly the painting was no longer important. The artist mixed himself a strong drink.

Unexpected version

The artist was concerned about having his painting ready for the exhibit deadline. While he was busily painting one day, he received a phone call. The artist was told he had three more months. He was shocked to hear this kind of news from his doctor. Although he had not been feeling well, he still had not expected to hear such bad news. His doctor expressed sympathy and hung up. Suddenly, the painting was no longer important. The artist mixed himself a stiff drink.

Target fact question

The artist was told he had three more months to do what?

received "while busily working one day" presented him with the news that he had three more months to *live*. There were three different versions of each passage, including one which stated the target fact directly (Explicit version) and two (the Expected and Unexpected versions) which required inferences for encoding the target fact. The Expected passages provided strong contextual support for the target inference from their beginning; the Unexpected versions did not and, in fact, tended to initially elicit an alternative interpretation of the situation (e.g., that the artist had three more months to *finish* the painting he was working on). In the Unexpected but not in the Expected passages, generation of the target inference was presumed to require a reevaluation of the encoding initially assigned and retrieval of sufficient passage information to resolve the discrepancy in understanding. Because of the working memory demands of this process, age deficits were expected to be largest for Unexpected passages. The limited demands on the storage function of working memory made by the Expected passages might be insufficient to disrupt younger adults but sufficient to disrupt inference formation in older adults. Because no particular demand is placed on storage capacity for encoding the target information in the Explicit passages, no age differences were expected.

These expectations have been largely confimed in experiments in which subjects listened to or read a series of such passages under comprehension instructions and then were tested using direct questions (e.g., "The artist had three more months to do what?"). These studies also used similar questions to test recall of two factual, explicitly presented control details for each passage. Based on the large literature showing age differences on detailed information that is not central to the understanding of a message, we expected to find age differences on these items across all three types of passages.

Across the studies, materials were presented in one of three ways. In Zacks *et al.* (1987), subjects listened to the passages, read at a comfortable, preset rate of presentation which was not under the subjects' control. In a second (see Zacks & Hasher, 1988), subjects read the materials themselves and controlled the rate of presentation by pressing a key on a computer to present the next sentence on a screen. In this study (and a third, which also used a self-paced presentation procedure), we could examine reading rate data for individual sentences in the different passage versions. The second two studies differed from each other in that the presentation method in one (Zacks & Hasher, 1988) simulated an auditory presentation mode in which there was no access to previous information, except via one's own memory, once a sentence disappeared from the screen (this was termed a "noncumulative" presentation procedure). In the other, the presentation method simulated, at least within each passage, a standard reading procedure in which each new sentence joined, rather than replaced, the preceding sentences (this was called a "cumulative" presentation procedure). Such a procedure provides an "external memory" and, if our working memory capacity rationale is correct, an external memory should eliminate the need to rely on the storage component of working memory which, in turn, should eliminate age differences even in the most demanding condition (the Unexpected passages) because the participants no longer need to rely on their own memories.[5]

Across the three experiments, the procedures (other than those concerning the presentation method and timing controls) were basically the same. Subjects read one version of each of the 12 passages, with four from each of the conditions (Explicit, Expected, and Unexpected). Across subjects, passages were counterbalanced so that each was used equally often in each condition of an experiment. The most critical point is that the *identical* target information was tested equally often in all three of the inference conditions. Subjects read or heard a series of six passages under oral presentation and 12 passages under written presentation and were then tested, in the order of initial presentation (which was varied across subjects) and in the presence of a passage title (e.g., "The Artist"), for their answers to three questions per passage, one concerning the target inference and two control details. The same procedure was followed for the remaining six passages.

In all three studies, the young subjects were university students who were mainly in their first 2 years of college. They were typically volunteers from a department subject pool and were not paid for their participation. The older adults, by contrast, were paid. In all but the first experiment, older participants ranged in age from 63 to 75 and most had some college education. In the first experiment, the upper limit was 90 years of age. Participants were tested either in a university-based laboratory setting or in a community-based setting arranged so as to simulate a laboratory. In either case, older participants arranged for their own transportation to participate in the testing. All subjects were administered the vocabulary subtest of the WAIS-R. There were 24 younger and older subjects in the oral presentation experiment, 60 in each age group for the noncumulative procedure, and 30 in each age group for the cumulative procedure.

The data on target recall are shown in Table II, with the difference score used as a shorthand measure to indicate the effect of age on each

[5]Details of the procedures used in the first two experiments may be found in Zacks *et al.* (1987) and in Zacks and Hasher (1988). We note that a portion of the third experiment reported here entailed a replication of the visually presented noncumulative procedure reported in Zacks and Hasher (1988). For ease of presentation, here we collapsed the two replications of the noncumulative procedure, creating one younger and one older group of 60 subjects each.

TABLE II

PERCENTAGE CORRECT RECALL OF TARGET INFORMATION AS A FUNCTION OF AGE, INFERENCE CONDITION, AND PRESENTATION MODE

Inference condition	Oral presentation (48 subjects/age group)			Written: Noncumulative (60 subjects/age group)			Written: Cumulative (30 subjects/age group)		
	Young	Old	Difference	Young	Old	Difference	Young	Old	Difference
Explicit	88.0	85.4	2.6	97.1	92.1	5.0	93.2	90.8	2.4
Expected	90.1	72.4	17.7	94.6	90.4	4.2	94.2	91.7	2.5
Unexpected	80.7	60.9	19.8	87.5	72.9	14.6	88.3	85.0	3.3

of the three inference conditions. These data yield two important conclusions. The first is that in all cases, age differences are small and nonsignificant for target facts presented in Explicit passages, indicating that older and younger adults are equally able to encode *and retrieve* the centrally important target facts when they are actually presented. Futhermore, with *identical* information having been tested in the implicit conditions, any age differences in these conditions are most readily interpreted as being due to encoding differences. That is, older adults have greater difficulty forming inferences, even ones such as those used here, which are central to an understanding of a passage.

The second major conclusion is that the age differences found in inference generation are a function of presentation mode and/or pacing as well as inference difficulty. In particular, with oral presentation [and no control over pacing (Experiment 1)], there are large and reliable age deficits for both easy and hard inferences. With the self-paced noncumulative presentation mode, only the Unexpected inferences show a deficit; older and younger adults no longer differ in their likelihood of forming an Expected inference. With the self-paced, cumulative presentation used in the final experiment, there is no age deficit in target recall even for the Unexpected passages.

In all three experiments, recall of the *control* facts was lower (by 8–21%) for older than for younger adults. The size of the age difference was somewhat smaller with written than with oral presentation, but was unsystematically related to inference condition.

Information on how the pattern of recall of target inferences comes about can be derived from the reading times in the two self-paced conditions using cumulative and noncumulative presentations. Table III presents the reading times per word for each of two sentences, called Critical

TABLE III

READING TIME (IN MSEC/WORD) FOR INFERENCE, CRITICAL, AND POSTCRITICAL SENTENCES

Sentence	Noncumulative[a]			Cumulative[b]		
	Explicit	Expected	Unexpected	Explicit	Expected	Unexpected
Younger subjects						
Critical	361	369	451	449	455	590
Postcritical	323	350	404	341	346	461
Older subjects						
Critical	520	514	585	532	583	790
Postcritical	432	449	503	483	584	681

[a] n = 60/age group.
[b] n = 30/age group.

and Postcritical. For participants receiving the Unexpected version of a passage, the Critical sentence contained the first direct indication that their current understanding was incorrect. For example, in "The Artist," the sentence "He was shocked to hear this kind of news from his doctor" made it clear that "the three months" did not concern a painting deadline. The postcritical sentence was the immediately following sentence in each passage. For the Explicit and Expected versions of a passage, the information in the Critical sentence was not particularly surprising, nor was it new. Rather, it fit well with subjects' current interpretation of the passage. Thus, reading time for the Critical sentence in these two conditions can be considered a baseline against which to assess the effects of information that, in the Unexpected version, leads to a reconsideration of the appropriate interpretation of the passage.

Consider first the data from the Noncumulative presentation condition. Both older and younger adults slowed their reading of the Unexpected passages when they came to the Critical sentence which first clued the target inference. Although the magnitude of the slowdown is approximately equal for younger and older participants, younger adults were nonetheless more likely to form and remember this inference than were older adults (see Table II). Thus, time alone is not the critical factor in inference formation. Either or both of two alternatives must be considered as the potential source of the failure of the slowdown to result in satisfactory inference formation: (1) older adults suffer from an inability to quickly retrieve information no longer in working memory and/or (2) although they can retrieve the information they have trouble doing the reconsideration necessary to establish the inference in the Unexpected passages.

The data from the Cumulative presentation condition are helpful in suggesting the locus of this deficit.

We note first that the provision of additional information in the Cumulative condition slows down reading somewhat for both younger and older subjects, as is clearly seen for the Critical sentence. This slowdown is apparent throughout the passage after the initial sentence. Of special interest here is the slowdown in the Unexpected versions: it is larger in the Cumulative condition than in the Noncumulative condition, suggesting that both younger and older subjects pause at this point in the passage to consult preceding information that is physically available on the computer screen. Especially noteworthy in these data is the fact that the slowdown in the Unexpected version is substantially larger for older than for younger adults. Recall that in this condition only (Table II) is there evidence that older adults can form and remember the central inference in the Unexpected version as successfully as younger adults. It is clear then, that when the relevant information is provided and is available, older adults have little trouble with the logical work necessary to accommodate the change in understanding that is required under the Unexpected condition (a similar conclusion on reasoning may be found in Light *et al.*, 1982). By exclusion then, the fundamental problem older adults seem to have in dealing with these passages (and potentially in a wide range of other materials and tasks) is their relative inability to retrieve needed information.

B. Priming Studies

1. *Experiment 4*

The suggestion from the inference studies is that, unless conditions are optimal, older adults have difficulty retrieving sufficient information into working memory to form the difficult Unexpected inferences. The next set of studies focuses on possible age deficits in retrieval of prior information. In general, we expected to find such deficits primarily when demands on working memory capacity were fairly high. In particular, in the first of the studies, which examined the ability of a word to cue (or prime) the retrieval of another word from a recently presented sentence, we did not expect an age difference. Because only short sentences were used in the study, if a sentence was remembered, its activation by a cue should allow the whole sentence to be as available in the working memory of older as of younger participants.

The procedure of this experiment was modeled after that of Ratcliff and McKoon (1981, Experiment 2). In each of 24 blocks of trials, subjects were first presented (at a 4-sec rate) six unrelated noun$_1$–verb–noun$_2$ sentences (e.g., "The scientist nudged the sheriff"). Then they performed a recognition test on nouns from the preceding set of sentences. Each test noun was paired with a word that served as a "prime." In the conditions of greatest interest, the test nouns had appeared in one of the preceding six sentences and the prime was either the other noun from the same sentence (*Within* prime) or a noun from another of the five sentences (*Between* prime). If a prime cues the retrieval of its sentence, subjects should be able to recognize test words more quickly in the Within- than in the Between-prime condition (the Priming effect). Different groups of 24 younger and older adults were tested with delays (SOAs) of 300 or 1000 msec between the onset of the prime word and the onset of the test noun. The primary dependent measure was the reaction time for correct recognitions of the test word. These data are summarized in Table IV, where "forward" priming refers to cases in which $noun_1$ primed $noun_2$ and "backward" priming refers to the reverse situation. This is of potential interest because a different pattern of forward vs. backward priming for the two age groups might indicate age differences in the memory structures of the sentences. Ratcliff and McKoon's (1981) finding of equal forward and backward priming for young adults suggests that this age group stores the sentences in memory in an abstract, nondirectional form (cf. Howard, Heisey, & Shaw, 1986).

The priming effect in Table IV (the faster response times for Within as compared to Between primes) varies somewhat across conditions, but statistical analysis shows that significant priming is obtained for both ages at both SOAs and in the backward as well as the forward direction. Using a slightly different paradigm, Howard *et al.* (1986) recently obtained similar results, except that their older adults showed no priming for sentences

TABLE IV

MEAN RECOGNITION TIMES (IN MSEC) AS A FUNCTION OF AGE, SOA, AND PRIME TYPE

	Forward priming			Backward priming		
Group	Within prime	Between prime	Priming effect	Within prime	Between prime	Priming effect
Young						
300 SOA	674	696	22	670	697	27
1000 SOA	640	701	61	632	699	67
Old						
300 SOA	918	941	23	891	966	75
1000 SOA	919	985	66	923	947	24

presented once, whereas ours did. The conflicting results are probably due to differences in list length and test delay. We tested subjects after each set of six sentences; they tested them only at the end of a long list. In any case, both sets of findings suggest that older adults can retrieve into working memory an entire sentence, if that sentence is short enough and if it is accessible in long-term memory. The equal forward and backward priming for both age groups further indicates that the stimulus sentences have similar memorial structures across the age groups. The question of the limits of sentence complexity or length for which this is true is left for future work.

2. *Experiment 5*

The next experiment also assessed retrieval using a priming procedure, one developed by Dell, McKoon, and Ratcliff (1983) that measures priming *on-line* during a speeded text-processing task. This time the question was whether a prime (an anaphor) could retrieve information from a preceding sentence (the antecedent). In this study, as in the original Dell *et al.* study, there were pre-existing relations between the prime (e.g., pet) and the antecedent target (e.g., cat) information. If there were an age-related decline in priming using such materials, this would predict even less priming on-line for older adults when the prime–antecedent relation is newly established by the text.

Although the procedure of this experiment has received some criticism, careful examination has established its validity (O'Brien, Duffy, & Myers, 1986). In it, subjects read paragraphs whose initial sentences introduce an antecedent (e.g., cat) which will, some sentences later, be referred to by an anaphor (e.g., pet). The question is whether the presentation of the anaphor reminds the subject of the antecedent, and if so, how quickly. This is asked in an on-line situation such that the test of whether or not reminding is successful occurs at different points within a critical sentence in which the anaphor or its control word (a word that meaningfully fits into the sentence and has about the same frequency of occurrence in the language but that does not point to the antecedent) is presented as the second word. In our variant of the procedure, the test of activation (essentially how long it takes the subject to recognize that a target word, *cat*, was actually in the current paragraph) occurred following either the prime or its control by 250-, 500-, or 750-msec time intervals that were filled with the presentation of the remainder of the sentence.

As can be seen in Table V, the data are quite straightforward. As in previous research, there was speeded reminding of an antecedent for young adults at all tested points during sentence comprehension. Thus, an anaphor activates its antecedent and that activation remains available at least

TABLE V

TIME OF CORRECT REFERENT RECOGNITIONS AS A FUNCTION OF AGE, CUEING CONDITION, AND TIMING OF TEST[a]

	Younger			Older		
Condition	250	500	750	250	500	750
Anaphor	613	553	636	1047	965	979
Control	651	638	670	1025	1016	1063
Effect	38	85	34	−22	51	84

[a]Delay from anaphor in msec.

throughout a relevant sentence. This is critical given the substantial evidence that although some interpretational processes occur on-line in a word-by-word manner (the "immediacy hypothesis"), there is also processing that is held in abeyance until the sentence boundary. Such "wrap-up" processing may be particularly critical for the establishment of coreference across sentences that is critical for an integrated representation of a message (see Just & Carpenter, 1987 for a recent overview of these arguments).

Older adults produced a rather dramatically different priming pattern. They showed no reliable priming 250 msec after an anaphor; priming was not reliable until 500 msec later. Failure to find semantic priming for older adults at short SOAs has been reported before (Howard *et al.*, 1986), although some success has been reported as well (Light & Albertson, 1988).[6] Thus, even when there is a strong, preexisting connection between words in a passage, older adults are slower to gain access to an antecedent. This can easily limit the quality of understanding that older adults can produce in on-line comprehension. Such persistent slowing might eventually lead to a strategy of failing to search. Recall from the reading time data in the inference study that older adults in the Noncumulative condition (where retrieval was required for successful completion of the inference in the Unexpected version) spent approximately the same amount of time

[6]The source of the discrepancy between the two studies is unclear. The procedures used were very similar, in part because Leah Light generously provided us with the computer program. Thus, the differences seem most likely to reside in aspects of the materials (e.g., in the strength of the preexisting connections between the anaphors and their referents) or the subjects. Light and collaborators' subjects tend to come from a very highly able sample, to judge from WAIS vocabulary scores which are often above a mean of 65 and sometimes above a mean of 70. Our samples of older adults, in order to match our sample of younger adults, have mean WAIS vocabulary scores that range from the mid-40s to the mid-50s.

on the critical sentence as did the more successful younger adults. This equal search time may be the product of an invariance across the adult life span in subjectively permissible search times, or it may be the product of considerable experience with retrieval failures.

C. Empirical Conclusions

The major conclusions from these studies are clear. The ease of inference formation for older adults varies with demands tied to pacing and to the need to retrieve information from memory. With information presented at a standard speaking rate (at least for young adults), older adults have trouble forming both easy and hard inferences. With control over pacing, older adults continue to have difficulty with just the hard, memory-demanding inferences. This difficulty disappears when older adults no longer need to rely on their own memories for retrieval. Retrieval problems can be seen clearly in Experiment 5, in which older adults are slower to retrieve a cued (primed) word despite the existence of preexisting connections among words.

IV. Criticisms of the Reduced Processing Resource Approach

Although our findings and others in the literature (see e.g., Cohen, 1988; Light & Burke, 1988) are generally supportive of the idea that older adults have reduced capacity for cognitive processing, it may be time to reconsider the heavy reliance on reduced capacity views in cognitive gerontology and elsewhere. A number of factors are persuasive on the need for such a reevaluation. These include recent criticisms of limited capacity views in general (e.g., Allport, 1987; Hirst & Kalmar, 1987; Navon, 1984; Neumann, 1987) and of their application to accounts of age-related changes in cognition (e.g., Light, 1988; Salthouse, 1982). It seems clear that the causes of age changes in cognition are more complex than reduced capacity views assume. For example, these views ignore the social and affective concomitants of aging and the impact these factors might have on performance in cognitive tasks (cf. LaBouvie-Vief & Blanchard-Fields, 1982).

As others have discussed in detail and as we therefore review briefly, there are serious conceptual and empirical shortcomings to the limited capacity approach. One problem is the lack of agreement, and often the lack of specification, of the nature of the central *resource* that is limited in quantity. For example, Craik (1983) deals with processing resources in a way that suggests an energy metaphor. Our working model, by contrast, suggests a space metaphor. Although it is difficult to determine whether these differing notions of capacity are contradictory, it is clear that they implicate different factors (e.g., effort vs. storage load) as determining resource demands. A second problem with current capacity views is the lack of agreement about (and frequently the lack of specification of) how capacity limitations and their presumed age-related reductions actually *impact* on mental functioning. Among the possibilities here are constraints on the amount of effortful, elaborative processing at encoding and retrieval (Craik's view) and constraints on active storage of information (our view).

Another controversial issue concerns whether the individual's limited resources should be thought of as a single pool of general-purpose processing resources or as a set of independent resource pools, each tied to a different mental function (Allport, 1987; Navon, 1984). In part, this controversy stems from failed attempts to develop broadly applicable measures of available capacity and of the capacity demands of different mental processes.[7] Consider, for example, the secondary task procedure, which may be the best of the available methods for capacity measurement. To determine the relative capacity demands of a set of primary mental tasks, subjects are required to perform each in conjunction with a standard secondary task, such as responding to a tone (e.g., Kerr, 1973). The slower the reaction time on the secondary task, the greater the presumed capacity demand of the concurrent primary task. The problems with this line of argument for single resource pool views are that different secondary tasks may give different rankings of the target primary tasks and that the amount of mutual interference between two primary tasks performed simultaneously is often inconsistent with estimates based on secondary task performance (e.g., Allport, 1987; Hirst & Kalmar, 1987; Navon, 1984).

Even the possibly less ambitious goal of finding a general measure of working memory capacity has proved elusive: Daneman and Carpenter's (1980) sentence span test has not, as was initially hoped, proved *broadly* useful as a predictor of individual differences across a range of cognitive tasks (although it appears to be extremely useful as a predictor of language comprehension; Carpenter & Just, 1988). Instead, the best predictor for different tasks may be a working memory measure that is fairly closely tied to each task (Daneman & Green, 1986; Daneman & Tardiff, 1987).

However, multiple resource pool views also have their problems. Such views are not readily accommodated to the fact that there is always some mutual interference when two tasks, even very different ones, must be performed together. Also, there is the difficulty, in the absence of a priori

[7]One serious consequence of the lack of a standard measure of capacity demands is the tendency to categorize mental operations as automatic or effortful on an ad hoc basis (cf. Light & Burke, 1988). In the aging literature, this tendency sometimes takes the form of arguing that automaticity is demonstrated by age invariance while effortfulness is demostrated by age change, a line of argument which is clearly circular if age comparisons are the sole basis of classification.

criteria, of determining the number of different pools an adequate model must include.

We do not intend to imply with these criticisms of the limited capacity notion that it has not been useful in cognitive psychology. Indeed, it has been an extremely powerful idea. In the cognitive gerontology literature, in particular, it has helped organize and make comprehensible complex (and on the surface, possibly conflicting) sets of findings. It has also generated much interesting research. The criticisms, however, clearly suggest that a new direction in theory development is required.

As a first step toward motivating the particular direction our theorizing has recently taken, we raise a number of additional issues which are not so much criticisms of reduced capacity views as questions that either are not addressed or are not adequately answered by such views. The theoretical approach we present in the next section includes potential answers to these questions.

One question is *why* working memory capacity (or any other mental resource) should decline with increasing age. Possibly relevant here is the obvious mental slowing that occurs as we grow older. Some (e.g., Cohen, 1988) have conceived processing resources in terms of speed of processing. Taken to an extreme (e.g., Salthouse, 1982), such views imply that mental slowing is the fundamental cause of age declines, with the apparent capacity losses being a consequence of the cognitive slowing. The opposite position is, of course, also possible, and, in fact, differentiating between them may be very difficult (cf. Salthouse, 1985). In any case, it is probably foolhardy to ignore mental slowing phenomena.

Another issue concerns the potential impact of noncognitive age differences—for example, in values, goals, and interests—on the cognitive performance of older adults. LaBouvie-Vief and collaborators (e.g., LaBouvie-Vief & Blanchard-Fields, 1982) have argued that the "poorer" performance of older adults on cognitive tasks is, at least in part, a result of factors such as lack of interest in the tasks or performance goals that do not match the investigator's criteria of good performance. For example, older adults may try to recall a story in a way that is interesting rather than in a way that is as true to the original as possible (e.g., Arbuckle & Harsany, 1985). Cognitive psychologists have, perhaps, too fully ignored this type of claim.

As a final step in motivating our new theoretical orientation, we report some findings that were germane to our thinking. These findings come from Verneda Hamm's dissertation, now nearing completion at Temple University. In a study using the inference difficulty passages, she attempted to determine what subjects were thinking about at key times in their reading of these passages (1) near the midpoint, prior to the time at which subjects in the Unexpected version would learn that they had the wrong understanding, or (2) at the end of the story. She did this by asking subjects to make a speeded decision to an individual word which was either the final, Target inference, or the initial, Competing inference from the Unexpected versions. (For "The Artist," the two words would be *live* and *finish*, respectively.) The passages were presented on a computer screen for self-paced reading. When, on occasion, a single word appeared on the screen, the subjects were to decide whether or not that word was *consistent* with their current understanding of the passage. Subjects read a total of 24 passages, half each in the Expected and the Unexpected formats. Consistency judgments were made either midway through or at the end of the passage.

On Expected passages, younger and older subjects were highly similar in their responses. Both groups judged the target inference to be consistent with their interpretation at both the midpoint and at the end of the passage (although the agreement figure increased from a midpoint value of 67% to a final value of 90%). For the Unexpected passages, by contrast, the two age groups were quite different. At the midpoint of the Unexpected version, younger subjects were more likely than older subjects (81 vs. 72%) to judge the competing inference (*finish*) to be consistent with their understanding. This suggests that given the limited context provided at the beginning of the Unexpected versions, older adults have a more difficult time generating an appropriate inference. By the end of the passage, younger and older subjects judged the Target inference as consistent with their current interpretation equally often (90% and 88%, respectively).

The most intriguing finding was the outcome of those trials in which subjects were tested at the end of an Unexpected passage with the competing inference: Young subjects judged those items to be consistent with their interpretation 28% of the time. Older adults judged those same items to be consistent fully 48% of the time. Thus, although *live* was more likely to be consistent with a reader's understanding at the end of the Unexpected version of "The Artist" than was *finish*, *finish* nonetheless retained greater credibility for older adults than it did for younger adults. It is as if older adults, having formed an inference, are slower and/or more reluctant than younger adults to give it up even when, as the data indicate, they have arrived at a more appropriate one. That older adults are more likely than younger adults to maintain *both* inferences for Unexpected passages is clearly at variance with a view (such as our initial one) that assumes that older adults have less storage capacity in working memory. If anything, the reduced working memory capacity position would have suggested the opposite pattern of data across ages. The unexpected nature of Hamm's results suggested a hitherto unsuspected source of differential disruption between younger and older adults. This source, an age-related decline in the efficiency of inhibitory processes, is incorporated in the modified theoretical framework to which we now turn.

V. A New Framework: Inhibition and the Contents of Working Memory

We begin with the assumption that working memory is centrally involved in comprehension. Now, however, we focus on the contents of working memory rather than on its capacity. Central to the efficient operation of working memory, and to selective and intensive attention as well (e.g., Neumann, 1987), are inhibitory mechanisms which, when normally functioning, serve to limit entrance into working memory to information that is along the "goal path" of comprehension. This refers to information necessary to the establishment of an objective understanding of a message, one which largely coincides with the intentions of the speaker or writer.[8] By contrast, off-goal-path ideas are irrelevant or peripheral to the formation of a coherent and detailed representation of a text. Because attentional gating will not be perfect, non-goal-path information, such as personally relevant thoughts, contextually inappropriate interpretations of words or phrases having multiple meanings, and daydreams, may on occasion enter working memory. When they do, normally functioning inhibitory mechanisms will rapidly dampen the activation of the non-goal-path thoughts.

When the goal of the listener is not restricted to the establishment of the objective meaning of the message, the comprehension situation will be slightly altered from that just described. This is because the goals of the reader or listener are critical determinants of what is and is not inhibited (see Navon, 1986). With respect to older adults whose interests, values, beliefs, and goals may be different from those of younger adults, this issue assumes particular importance. If there is an age-related increase in the importance of one's personal values and experiences along with an age-related increase in the tendency to apply these concerns to a wider range of information, more information that is off the goal path of establishing objective meaning is almost certainly likely to enter working memory. We turn now to consider what might happen if inhibitory mechanisms malfunction or become inefficient, as might occur whenever central neural functioning is slowed and/or when goals differ from the determination of objective meaning.

[8]A listener may have goals other than that of extracting the objective meaning of a message. Such goals might be enacted when one tries to be polite to a bore or when one tries to discern the "hidden agenda" of a meeting or conversation.

Breakdowns in the efficiency of inhibitory processes may have profound consequences. In parallel-architecture attention systems, a breakdown in inhibition will lead to cross talk among simultaneously active messages, preventing organized responses. Behavioral consequences may include such abnormal examples as schizophrenia and attention deficit disorder (see e.g., Posner, 1987). But the consequences of inefficient inhibition need not be so profound as these in order to limit comprehension and memory. Consider what happens (as we suggest occurs with normal aging, when inhibitory mechanisms become inefficient) when goals change (see Fig. 1).

Inefficient inhibition will enable the initial entrance into working memory of information that is off the goal path. It will also result in the prolonged maintenance of such information in working memory. At least three categories of off-goal-path thoughts may be identified: irrelevant environmental details, personalistic memories or concerns, and off-goal-path interpretations. Thoughts about irrelevant contextual and/or environmental details *might* occur when one listens to a research presentation, loses track of the message, and begins to wonder about the speaker rather than the content of the talk: "I wonder if her squash game is still good?" or "This auditorium looks like a pig sty: imagine what the dorms must look like!" Or the thoughts might be highly personalistic ones that involve particular events ("Remember the time we all went to the pier instead of the meeting?"), plans (I better remember to make dinner reservations right after the talk"), or evaluations ("This is not the best talk he's ever given, but the ideas are interesting"). These might be initiated by something in the content of a primary input (perhaps even a minor detail, as when a footnote acknowledging that an experiment carried out during a sabbatical at an English university initiates thoughts about one's own visit there) or by something in the environment.

A final category of activated responses encompasses responses tied to

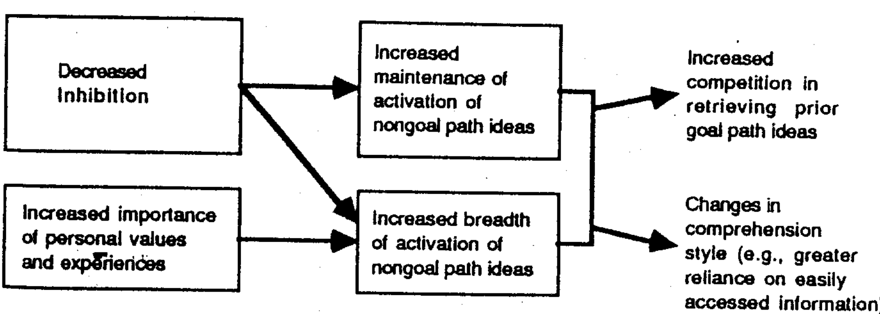

Fig. 1. Discourse processing effects of reduced inhibitory efficiency: a theoretical framework.

the linguistic message itself but not on the ultimate goal path. These include the activation of contextually irrelevant meanings of words or phrases, as occurs when the *bank* being discussed is a financial institution but the listener briefly considers a geological formation (Simpson, 1984). Contextually irrelevant meanings also occur to accidental and intentional garden-path messages (as is true for the Unexpected passages in our inference studies) when the initial interpretation the listener or reader assigns is plausible but not the one the communicator intended. Consider the following example: "The assistant baseball coach reached into the equipment cabinet and saw the bat that was trying to get out."

What are the consequences of the entrance into working memory of irrelevant information? Obviously, these will depend on the degree of concentration (or the intensity of attention) accorded the off-goal-path information. If this assumes the proportions accorded fascinating daydreams (e.g., Klinger, 1978), some goal path aspects of the message will go unprocessed. This may result in an awkward pause in a conversation when the listener fails to nod or articulate appropriate interest or encouragement. Or in reading, one may realize that although the eyes have moved down the page, little information has been absorbed (see Just & Carpenter, 1987). These are probably extreme examples of what can happen when attention is directed to irrelevant information. Indeed, these examples may be the self-generated analogs of what happens when the reader/listener has so little appropriate knowledge accessible that he or she is unable to establish coreference among the phrases and sentences of a passage (e.g., Bransford & Johnson, 1972). The determination of coreference is a fundamental requirement for the establishment of a coherent representation of a complex message. Coherent representations, in turn, play a major role in one's sense of comprehending a message as well as in determining the ease or likelihood of recall of that message (Bransford & Johnson, 1972), if not necessarily of its recognition (e.g., Alba, Alexander, Hasher, & Caniglia, 1981).

Another consequence of decreased inhibitory functioning will be a reduction in the ability to switch attention from one target or category of events to another (e.g., Logan, 1985; Posner, 1987). For discourse comprehension, this suggests that changes in the scene or setting of a text or in some other aspects of a mental model (Sanford & Garrod, 1981; van Dijk & Kintsch, 1983; Johnson-Laird, 1983) should be particularly difficult to respond to for those with diminished inhibitory mechanisms. Thus, narrative passages containing many scene changes may pose particular problems.

The argument to this point is that the inefficiency of inhibitory mechanisms sets up the circumstances that permit more objectively irrelevant information to enter working memory and, once it has entered, permits the irrelevant information to receive more sustained activation than it otherwise would. This combination of events creates the ideal circumstances for the operation of at least two classic mechanisms of forgetting: (1) weaker or poorer quality initial encodings (e.g., Hasher, Griffin, & Johnson, 1977) and (2) competition among related ideas (e.g., Postman & Hasher, 1972). Although our central interest is with competition at retrieval, these two sources of forgetting are not independent. Ideas that cannot be retrieved due to poor encoding and/or competition cannot enter into distributed rehearsal cycles, and these are critical both to the development of integrated representations (e.g., macrostructures, Kintsch & van Dijk, 1978) and to the ultimate likelihood of recall (e.g., Hasher & Griffin, 1978; Keppel, 1967).

We are proposing that reductions in inhibition "enrich" the contents of working memory with more non-goal-path information, which, in turn, creates the conditions necessary for competition at retrieval. Heightened competition is the direct consequence of the greater timesharing that reduced inhibition permits for off- and on-goal-path information. These categories of information will be linked in memory as a result of their temporal proximity in working memory in such a way as to serve as sources of mutual competition at retrieval. Thus, the off-path information may be able to prevent, at least momentarily, access to target information. Depending on the nature of this target information, a failure to retrieve it can be more-or-less damaging to comprehension. Suppose the target (which co-occurred with irrelevant thoughts about a friend whose behavior was similar to that of a main character) is the referent of a subsequent pronoun. The failure to retrieve the target in a timely manner because of competition from the irrelevant thought will limit the reader/listener's ability to establish coreference and, so, will limit his or her ability to establish a coherent representation.

In on-line comprehension, sources of self-generated competition include any non-goal-path antecedent or interpolated thoughts that enter working memory. Thus, the greater amount of non-goal-path information that is reflected on by persons (such as older adults) with reduced inhibitory functioning sets the stage for an increase in a major source of temporary forgetting. The resulting reduction in access to antecedent information may be particularly disruptive whenever performance conditions (e.g., rapid pacing) increase competition. Indeed, discourse presented at faster as compared to slower rates is differentially disruptive for older adults (Stine & Wingfield, 1987).

Thus, a person with reduced inhibitory functioning can be expected to show more distractibility, to make more inappropriate responses and/or to take longer to make competing appropriate responses, and, finally, to be more forgetful than others. Existing evidence in the cognitive gerontology literature suggests that the behavior of older adults is consistent with the expectations that stem from a diminished inhibition view. In fact, the increased presence of irrelevant thoughts in working memory (and the attendant consequences) may well be the factors that produce the behaviors that have made it appear as if older adults have reduced capacity for cognitive functions.

Anecdotal evidence on the failure of older adults to inhibit non-goal-path thoughts comes from observations of their tendencies to infuse conversations with personalistic intrusions (see Obler, 1980). These may represent a combination of heightened interest in non-goal-path thoughts as well as reduced ability to inhibit those thoughts. More substantial evidence of age-related decreases in inhibition of thoughts can be seen in increased intrusion rates in free recall (e.g., Stine & Wingfield, 1987), in heightened rates of false recognition responses to semantic associates of actually presented words (Rankin & Kausler, 1979; Smith, 1975), and in reduced ability to inhibit both well-practiced and newly learned response patterns in order to acquire a new one (e.g., Hess, 1982, Experiment 3; Kausler & Hakami, 1982). In the semantic memory literature (see Nebes, Boller, & Holland, 1986, Experiment 2), there is evidence that older adults are less successful in dampening an activated thought when it is inappropriate for the situation than are younger adults. Thus, the empirical basis for the assumption of an age-related breakdown in the ability to inhibit thoughts is suggestive.

Evidence also suggests an age-related decline in the ability to inhibit responses to actually presented stimuli. Consider the Stroop procedure: it demands inhibitory control of responses in the version in which both the name of the printed word and the color of the ink the word is printed in are activated. The former response must be inhibited so that the latter can be produced. The Stroop interference effect increases with age (Cohn, Dustman, & Bradford, 1984; Comalli, Wapner, & Werner, 1962), suggesting a diminution of inhibition that operates on responses to actually presented stimuli. Research on visual selective attention (see Plude & Hoyer, 1985) suggests that when there is some degree of spatial uncertainty about the location of a target, an increase in the number of distractors in an array will slow target detection more for older adults than for younger adults (e.g., Madden, 1983; Plude & Hoyer, 1985; Scialfa, Kline, & Lyman, 1987, but see Madden, 1983, for an alternative interpretation). Thus, there is evidence that "noise" in the environment poses particular problems for older adults (Layton, 1975; Welford, 1984), problem that may stem from the inefficient functioning of inhibitory mechanisms.

We turn now to a brief consideration of evidence consistent with the view that retrieval problems contribute substantially to age-related deficits in memory. Indeed, this view is widely argued in the cognitive gerontology literature (e.g., Burke & Light, 1981; Till, 1985). A strong argument can be made that on-line retrieval failures lie at the heart of inference failures reported for older adults (e.g., Light & Capps, 1986, as well as data reported here). These failures are consistent with earlier research showing that when the level of original learning is *not* held constant, older adults suffer more from the classic sources of forgetting identified by interference theory (see Kausler, 1982; Hess, 1982, Experiment 3).

COMPENSATORY MECHANISMS

If older adults have profound retrieval problems that diminish even online comprehension, one might be tempted to ask how it is that older adults can function at all? Not only is it clear from personal experience that impairment is often far from overwhelming, but the empirical literature is also clear on this point. Indeed, a major observation of age-related performance is the increase in variability among participants. As well, age differences are more pronounced for tasks that require speeded responding than for others (e.g., Stine *et al.*, 1986). And they are more pronounced for tasks requiring the participant to retrieve information from memory with relatively little contextual support from cues (see Craik, 1983). When contextual support is great and interference is minimal (as it may be in at least some implicit memory tasks, see Graf & Schachter, 1987), age differences are also minimal (see Light & Singh, 1987).

In the face of what may well be massive memory problems associated with the elevated competition at retrieval that is the inevitable consequence of an inefficient inhibitory system, how are we to understand the sustained functioning of many older adults, especially those of high verbal ability, as has often been reported in the empirical literature (see Zelinski & Gilewski, 1988)? We propose that the answer lies in the fact that repeated encounters with retrieval failures lead to reduced attempts to retrieve and, thus, to compensatory changes in comprehension styles that rely heavily on two sources of information for their effective functioning: (1) information that is easily accessed from memory and (2) information that is in the surrounding environment. Consider the two major memorial sources of easily accessible information. One includes the current contents of working memory. The other includes memories or thoughts that have (what in an earlier day would have been called) high levels of learning (probably the result of many, distributed practice trials). Both the traditional verbal learning literature as well as research on everyday memory (see Bahrick, Bahrick, & Wittlinger, 1975) show clearly the importance of these variables in influencing accessibility. For all of us, some personal experiences, some opinions, some values are particularly highly accessible. If relatively little of the recent input can be retrieved, these can be used to fill the interstices of a conversation. As noted earlier, older adults seem particularly likely to make personalistic productions a salient part of their conversation (Obler, 1980).

These concerns lead us to a reconsideration of the framework depicted in Fig. 1. There, we assumed that the increased importance of personal values and experiences alters the goals involved in determining what enters working memory. An alternative is that changes in goals with age are the *consequence* of increased experience with inhibition-produced retrieval failures, leading to an increased reliance on highly accessible (by virtue of practice) personal memories. The representation of the framework thus includes an arrow leading from changes in comprehension style back to the box representing the increased importance of personal information. At this point, as the question mark indicates, the issue is indeterminate.

But easily accessed memorial information can only account for some of the preserved skills that older adults show. What accounts for the rest? The answer lies with information that is in the current stimulus array or that can easily be made to become so, as do the contents of a nearby closet once the door is opened. Certainly, some cues in the environment will be excellent, direct cues to a stored memory. Indeed, we have known since McGeoch (1932) that one major determinant of memory performance is the degree of overlap along a similarity dimension between cues at an initial experience and those at another point in time (Tulving & Thomson, 1973). Thus, we speculate that the power of retrieval cues, coupled with predictability and redundancy in the environment, are likely to leave a person who must rely on such cues only modestly impaired in mental functioning in the real world, compared to someone who is easily able to search memory or to generate his or her own retrieval cues.

Indeed, there are several empirical findings which are consistent with the view that older adults rely more heavily on the immediate array than do younger adults. For example, they make greater use of context in priming tasks (Cohen & Faulkner, 1983), leading occasionally to larger priming effects for older adults than for younger adults (Balota & Duchek, 1988; Bowles & Poon, 1985). There are also findings consistent with the view that older adults rely more heavily on easily accessible memories than do younger adults: (1) they often make more intrusions in recall, most often ones that are consistent with the "theme" of the material (Arbuckle & Harsany, 1985; Stine & Wingfield, 1987; Mueller, Kausler, Faherty, Oliveri, 1980); (2) they make greater use of personal experience and knowledge in interpretations (Labouvie-Vief & Blanchard-Fields, 1982); and (3) they may be more likely than younger adults to make decisions based on plausibility rather than to search memory to retrieve a fact (Reder, Wible, & Martin, 1986).

Loosely speaking, this general view of the functioning of memory might be termed a "sloopy desk" model. If one is missing a particular, desired piece of information, one can either search through a filing system (analogous to a search of memory) or one can search through the perceptual array. If the array is rich (the desk is piled with pieces of information), there is a greater general likelihood of an effective retrieval cue occurring during a search of the immediate environs. Thus, if we ultimately learn that there is an age-related change in the degree to which memory vs. the environment is searched, this change can be viewed as a compensatory strategy.

Compensatory strategies may be used with different degrees of likelihood across the life span, largely as a function of the efficiency with which inhibitory mechanisms function, because these largely determine the facility with which memory can be searched. If a search through memory enables the sustained activation of too many off-goal-path ideas, competition will be too great to produce the target item with a high degree of regularity. There is no reason to assume that inhibitory problems are confined to elderly adults. Inhibitory problems may occur in the attentional mechanisms of depressed adults, attention deficit disordered children, and schizophrenics (see Posner, 1987). We suggest it is conceivable that environmentally driven retrieval (the product of breakdowns in inhibition) may occur for young adults during periods of sustained physical illness, high arousal, and, possibly, depression (see Jacobs & Nadel, 1985). The diminution of inhibitory processes during these periods may ultimately be identified as a key mechanism in memory.

To summarize, we discuss briefly the memory framework proposed here. The central assumption is that under some circumstances (most notably here, aging), the efficiency of the inhibitory processes that underlie selective attention is reduced. This decrement in inhibition allows more irrelevant information to enter working memory, and once entered, it allows the irrelevant information to receive sustained activation. This then sets the stage for subsequent reduced rates of success in accessing required information from memory. The consequences for discourse comprehension in particular may be profound because the establishment of a coherent representation of a message (and, thus, ultimately of understanding and recalling that message) hinges on the timely retrieval of information necessary to establish coreference among certain critical ideas. Repeated failures to successfully retrieve searched-for information in memory may set the stage for changes in cognitive styles, at least some of which may come to function as successful compensatory mechanisms.

The current approach can handle the considerable data that has been otherwise taken to support reduced capacity views. The approach also explicitly acknowledges the contribution of individual and group differences in personal values and interests to the regulation of the content of thought processes. We note that although the framework was devised in the context of research on older adults, its usefulness extends beyond that group. Indeed, it may be useful in developing an understanding of breakdowns in memory-dependent cognitive functions in physically and/or emotionally ill young adults as well as an understanding of individual differences in the likelihood of using memory searches vs. environmental searches as strategies for cognitive functioning.

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