Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Lawrence Erlbaum Associates.

T. A. (1993). Speed mediation of adult age differences in cognition. *Developmental* ... 738.

... Memory development throughout the lifespan: The role of ... (Eds.), *Life-span development and behavior, Vol. 5*

... es: An example from children's ... –264.

... *ologist*, 46, 606–620.

Simon, ... tion to age. *Journal of Experimental Psychology: Human* ...

Thompson, L. A., & Kliegl, R. ... usibility on memory: The role of time constraints during encoding. *Journal of Exp... ology: Learning, Memory, and Cognition, 17*, 542–555.

Townsend, J. T., & Ashby, F. G. (1983). *The stochastic modeling of elementary psychological processes*. Cambridge, England: Cambridge University Press.

Waugh, N. C., & Barr, R. (1980). Memory and mental tempo. In L. W. Poon, J. L. Fozard, L. Cermak, D. Arenberg, & L. W. Thompson (Eds.), *New directions in memory and aging* (pp. 251–260). Hillsdale, NJ: Lawrence Erlbaum Associates.

In F.E. Weinert & W. Schneider (Eds.)
Memory Performance and Competencies:
Issues in Growth and Development
1995, Hillsdale, NJ: Lawrence Erlbaum

Chapter 6

Processing Capacity and Its Role on the Relations Between Age and Memory

Timothy A. Salthouse
Georgia Institute of Technology

There are three goals of this chapter. The first is to discuss some of the assumptions inherent in the concept of processing capacity as it is applied to developmental phenomena. Because interpretations based on such constructs are difficult to evaluate, a second goal is to outline a scheme that can be used to classify and help understand the role of different methods of investigation in explanatory developmental research. The final goal is to briefly describe a program of research focused on one particular hypothesis. This hypothesis asserts that information-processing speed functions as a form of processing capacity that influences memory and other forms of cognitive functioning in the adult portion of the life span.

I am an outsider relative to most of the other contributors to this volume because my research focuses on changes in memory and other cognitive processes occurring across the adult portion of the life span, rather than those occurring from birth to maturity. Although the relevant phenomena take place over a much longer time, and there is no assurance that identical change mechanisms are operating, many of the same issues concerned with the description and explanation of cognitive change are important regardless of the segment of the life span under investigation. In particular, I believe that the classification scheme I discuss, and the importance of what I refer to as *Phase 2 research*, are equally applicable to childhood and adulthood.

PROCESSING CAPACITY

Adult age differences in memory are well documented, and memory problems are frequently mentioned behavioral characteristics associated with aging (Crook & Larrabee, 1990; Dixon & Hultsch, 1983; Hultsch, Hertzog, & Dixon, 1987). Although there is not yet any consensus regarding the causes of age-related memory declines in the adult years, several researchers suggested that the relation between age and memory (and between age and other cognitive functions) might be partially attributable to an age-related reduction in processing capacity or resources (e.g., Craik & Byrd, 1982; Hasher & Zacks, 1979; Salthouse, 1988a, 1988b). However, these speculations were controversial because the concept of *capacity* or *resources* was not explicitly defined, and the methods by which hypotheses based on processing capacity might be investigated were not specified.

The term *capacity* is particularly ambiguous because it has at least two distinct, relevant meanings. *Webster's Seventh New Collegiate Dictionary* (1972) contains the following two definitions: "... ability to hold, receive, store, or accommodate," and "... power to grasp and analyze ideas and cope with problems" (p. 123). The former definition has a connotation of basic processing efficiency, whereas the latter seems to refer to overall mental capability or competence. Speculations based on the second interpretation of capacity are unlikely to be meaningful because there is little value in attributing performance variations in a particular task to variations in an unspecified type of competence or capability. This usage may even be circular if the differences in capacity are inferred to exist on the basis of the same performance differences that capacity differences are used to explain (see Light & Burke, 1988; Salthouse, 1988a, 1988b).

For this reason, some variant of the first interpretation is usually intended when the term capacity is used in cognitive psychology. The fundamental assumption is that human cognition is limited by quantitative constraints on processing—or limitations of capacity—in addition to restrictions associated with the quantity, quality, or effective application of different types of knowledge (e.g., declarative and procedural). The relative importance of structural or capacity factors and knowledge factors will vary across tasks, but a basic premise of the processing capacity approach is that some individual differences in cognition are attributable to variations in parameters representing the efficiency of elementary processing.

Three characteristics of the processing capacity perspective should be noted. The first is that capacity limitations are assumed to be relevant to many different cognitive activities, and are not local, or restricted to a small number of tasks. In other words, the consequences of capacity limitations are postulated to be general rather than highly specific. However, processing capacity is not necessarily unitary because there is nothing inherent in this perspective that rules out the possibility of multiple capacities. Interpretations become more complicated when more than one capacity is postulated, but some degree of capacity independence or modularity is not inconsistent with the capacity perspective.

The second characteristic of the capacity perspective is that capacity limitations are assumed to be only one of several determinants of cognitive functioning, and should not be viewed as the exclusive source of all performance differences in any cognitive task. This perspective does not deny the existence of other factors contributing to developmental differences in memory or other cognitive functions, but maintains that capacity limitations could be an important influence on performance, in addition to any other influences that might be operating.

The third characteristic of the processing capacity perspective is that most theorists tend to think of processing capacity as an entity intermediate between neurophysiology and higher order cognition. For example, various characteristics of attention, such as its selectivity, divisibility, sustainability, or degree of inhibitory control have been discussed as possible candidates for the resources or capacity construct. In recent years, there has also been considerable interest in the efficiency or effectiveness of working memory as a fundamental processing resource or capacity. Another possibility, and one that I have been interested in for several years, is that processing speed may function as a basic type of capacity, perhaps in a manner analogous to how the clock rate of a computer serves as a crude index of the computer's power or capacity. Although the processing capacity construct could be interpreted in completely neurophysiological terms, an intermediate level of theorizing is generally preferred, because the linkage to cognitive performance is more plausible when the constructs are more similar to the phenomena to be explained.

Regardless of the manner in which it is conceptualized, speculations about the role of processing capacity need to be tested. That is, no matter how intriguing and potentially parsimonious the concept of processing capacity might be, interpretations based on this notion cannot be taken very seriously without convincing empirical evidence. The next section of the chapter is therefore devoted to a discussion of the different phases of research concerned with investigating the role of explanatory constructs, such as processing capacity, in cognitive development.

PROPOSED CLASSIFICATION OF DEVELOPMENTAL RESEARCH

Three phases of explanatory, as opposed to descriptive, developmental research can be distinguished. The phases are not mutually exclusive, nor necessarily sequential, because it is possible that research can address several phases simultaneously. Nevertheless, the phases appear to represent a logical, if not strictly chronological, progression.

Phase 1

The primary goal of Phase 1 research is to establish the existence of a relation between age and the relevant theoretical construct. Research in this phase often relies on a measure of performance from a specific task to provide an index of the construct. However, inferences about age relations in the construct can also be based on a contrast across experimental manipulations. In this case, a significant Age × Condition interaction would indicate that the critical construct, whose influence is presumed to vary across conditions, is particularly sensitive to age. Much of the aging and cognition research of the last 10 to 20 years was of one of these two types, in that the major purpose was to investigate relations between age and some hypothesized construct.

A list of some of the theoretical constructs that were investigated in this manner is presented in Fig. 6.1. However, the mere existence of such a large number of alternative or rival explanatory constructs constitutes a potential problem if there is no means of evaluating the importance of a particular construct on the relationship between age and memory. That is, even if reasonable arguments could be proposed regarding the influence of a specific factor on the relations between age and memory, empirical evidence is still needed to determine the contribution of that factor relative to other possible factors. Information of this type, and information about the relations of the factors to one another, can be provided from Phase 2 research.

Phase 2

Figure 6.2 illustrates that at least three relations are involved if a construct is hypothesized to contribute to the mediation of relations between age and memory. Because Phase 1 research is only concerned with the relation between age and the hypothesized mediating construct, it does not directly address the question of whether, and if so to what extent, that construct contributes to the age differences in memory. This issue can be examined in the second phase because a major purpose of Phase 2 is to determine the plausibility and importance of the relevant construct as a determinant, or mediator, of the relationship between age and memory.

Many variables and constructs are related to age, and it should not be assumed that because two variables are both related to age, one of those variables has a causal influence on the relations between age and the other variable. For example, grayness of hair or wrinkling of the skin are known to be associated with increased age, but neither of these variables may have any relation to performance on tests of memory or other cognitive functions. Only when the relationship of the hypothesized intervening variable to age and to a measure of memory are available, can one determine the role of the variable as a potential mediator of the influence of age on memory. (See Horn, 1982, for further discussion of this point, which Horn refers to as the "missing link issue.")

The number of potential mediators between age and memory is large, but it is unlikely that all of them operate in every situation. Moreover, even if several are operating simultaneously, they may not be equally important or powerful. Because one aspect of progress in science consists of discriminating relevant from

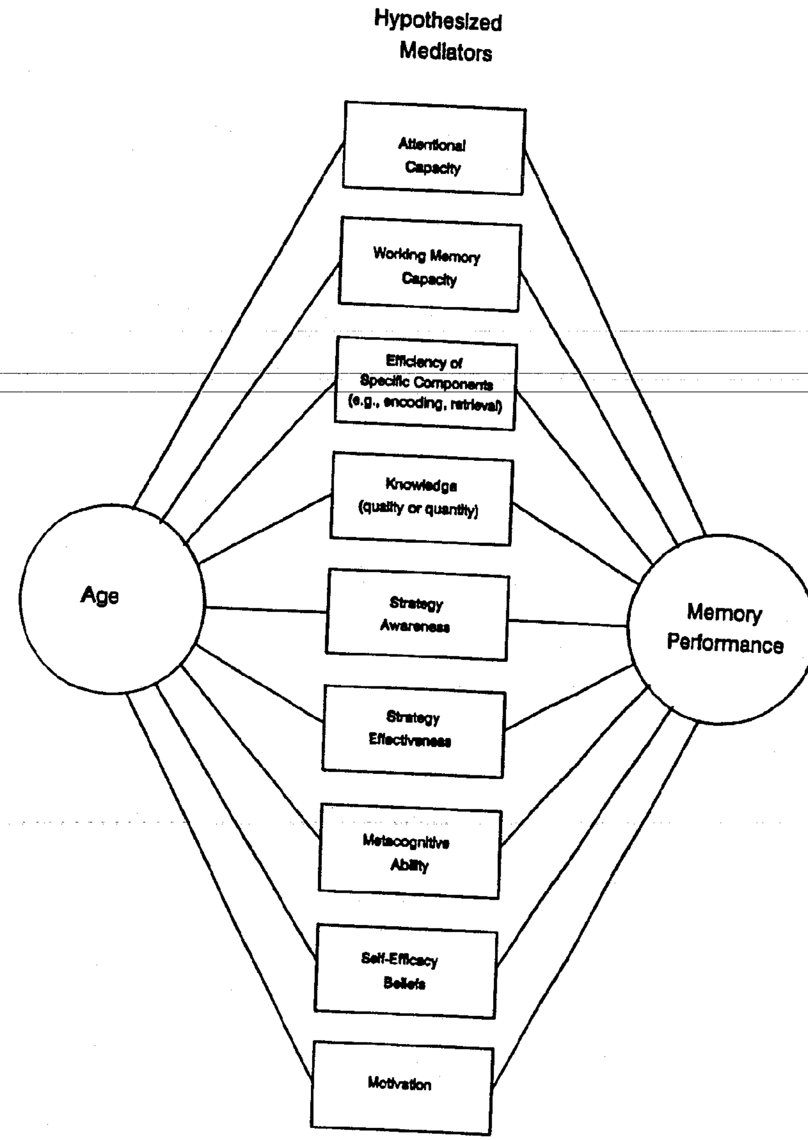

FIG. 6.1. Constructs hypothesized to contribute to relations between age and memory.

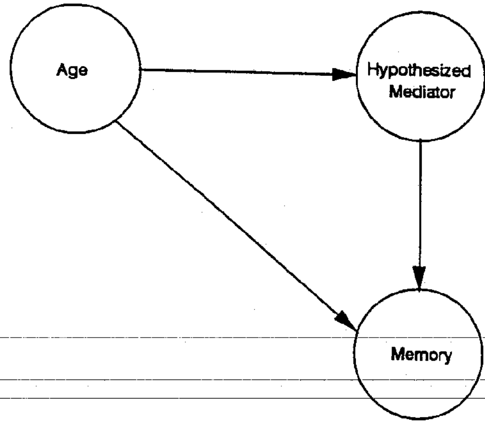

FIG. 6.2. Potential relations among age, memory, and a construct hypothesized to contribute to the mediation of the influence of age on memory.

irrelevant constructs, some means of eliminating extraneous or peripheral variables is necessary. A major purpose of Phase 2 research is to provide this type of information.

Another important function of Phase 2 research is to determine how various theoretical constructs are related to one another. Relations between constructs can be examined to verify that presumably distinct constructs are truly independent, and to determine whether or not the effects of one construct vary according to the level of other constructs. Among the specific issues that could be addressed in this manner are the empirical distinction between alternative conceptualizations of processing capacity (e.g., attention and working memory), and the relation between amount of processing capacity and aspects of higher order cognition, such as the usage of particular types of strategies.

Correlational data provide the primary source of information about the interrelations among variables in Phase 2 research. Because researchers who generally rely on experimental manipulations may not be very familiar with correlational procedures, two special requirements of this type of research should be noted. One requirement is that all relevant variables should be assessed in as reliable a fashion as possible because associations with other variables cannot be expected if the variables have little systematic variance. Reliability of a construct is enhanced by increasing the number of relevant observations, and by assessment with multiple measures (e.g., Rushton, Brainerd, & Pressley, 1983; Sullivan & Feldman, 1979). The use of multiple or converging operations also serves to increase the validity of measurement by minimizing influences extraneous to the theoretical construct, such as those associated with the particular methods, materials, or measures used in a given study.

A second requirement of correlational research is moderately large samples of research participants. This is necessary to increase the precision, in the sense of minimizing confidence intervals, of the estimated proportions of variance in each variable. That is, it is not simply statistical significance that is of primary interest in this type of research, but also the strength of the relevant relations, and sample sizes of 100 or more are often needed to obtain accurate estimates of strength of relationship.

Research with multiple measures and large samples is expensive and time-consuming, but it yields valuable information about the influence of specific theoretical constructs on the relations between age and memory. Although results from Phase 1 research are often interpreted as supporting the plausibility of a construct as a potential mediator of the relations between age and memory, Phase 2 research is required to establish that the construct actually does contribute to the influence of age on memory. Furthermore, because it is unlikely that any single factor would account for all of the age-related variance in a cognitive variable, it is desirable to use techniques that allow the relative importance of different factors or determinants to be evaluated. Such information can be derived from a variety of correlational procedures.

As an example, hierarchical regression analyses can be used to estimate the magnitude of the influence of the hypothesized construct on age-memory relations. That is, two separate regression equations can be constructed; one in which age is the only predictor of memory performance, and one in which age is entered in the equation after the construct hypothesized to function as a mediator. This latter equation indicates the unique age-related variance in the form of the increment in R^2 associated with age after the variance associated with the hypothesized mediating construct has been controlled, or removed by statistical means. The influence of the construct on the total age-related effects can then be determined by subtracting the unique age-related variance from the total age-related variance. This difference can be interpreted as an estimate of the contribution of the controlled variable to the relations between age and memory.

Other analytical techniques could obviously be used to evaluate the influence of a construct to age-memory relations. Regardless of the particular analytical method employed, however, a valuable outcome of Phase 2 research not provided in either Phase 1 or Phase 3, is information about the relative importance of the theoretical construct to the developmental phenomena of interest. If the hypothesized construct plays a major role in the relationship between age and memory, this influence should be demonstrable in the results of Phase 2 research. Furthermore, because the primary requirement of the analytical procedures is the availability of an index of the proposed mediating construct, the procedures are quite general and can be used with virtually any theoretical construct amenable to operationalization.

Correlational procedures can also be used to examine the relations among variables hypothesized to function as moderators or mediators of the relations between age and memory. For example, multiple regression analyses could reveal whether or not the effectiveness of a particular strategy varies according to the level of an index of some type of processing capacity. That is, a measure of strategy usage could serve as the criterion variable and an index of processing capacity could be entered as a control variable (to examine mediating influences), or as a cross-product interaction term with age (to examine moderating influences). Alternatively, patterns of relationships between indices of different conceptions of processing capacity could be examined with path analysis or latent construct structural modeling techniques.

Reservations are frequently expressed about inferences based on correlational data because correlations are equivocal with respect to causality. Correlations do not imply causation, and single-occasion correlational data are ambiguous about the direction of any causal influences that might be operating. Furthermore, many different structural models can usually be found to provide equivalent fits to a given set of data (e.g., MacCallum, Wegener, Uchino, & Fabrigar, 1993). Nevertheless, the presence or absence of a relation can be informative even if the direction of the relation cannot be determined from the available data. As an example, if one hypothesizes that age differences in memory are a function of differential strategy use, then a discovery that there was no significant relation between a measure of strategy use and memory performance would obviously be relevant to that hypothesis. Correlational data can therefore provide constraints on the types of hypotheses that might be viable, and in the process, yield information about the plausibility of specific hypotheses.

Phase 3

If the results of Phase 2 research indicate that the construct has plausibility as a potential mediator of the relations between age and memory, then the mechanisms responsible for the relevant relations need to be identified. In particular, attempts should be made to explain both the relation between age and the construct, and the relation between the construct and the measure of memory.

Correlational evidence from Phase 2 can indicate that the hypothesized relations exist and that the construct is likely to be involved in the influence of age on memory. However, correlational data are limited in the information they can provide regarding the processes or mechanisms responsible for those relations. Comparison of the strength of the relations with different combinations of variables can be informative, but other types of evidence are still desirable because of the ambiguity about causal direction inherent in most cross-sectional correlational research.

A wide variety of methods could be used to examine the mechanisms involved in the relations between age and the construct, and between the construct and memory. For example, experimental manipulations might be used to explore specific predictions, or various types of formal modeling could be used to establish the sufficiency of a particular mechanism for the construct–memory relation. Furthermore, certain types of neurophysiological evidence might be helpful in understanding the age–construct relation.

There is a sense in which Phase 3 research is a natural extension of Phase 1 research in that the focus in Phase 3 is explaining why the relations established in Phase 1 occur. However, an important difference between the two types of research is that the task of accounting for the relations is of much greater relevance when the evidence from Phase 2 research indicates that those relations are actually involved in the developmental phenomena of interest. That is, only when the results of Phase 2 are available can one have confidence that the theoretical construct really does contribute to the influence of age on memory.

PROCESSING SPEED AS A REFLECTION OF PROCESSING CAPACITY IN ADULTHOOD

In the remainder of this chapter, I briefly describe research in the three phases just outlined for a program of research designed to determine why increased age is associated with lower performance in various types of cognitive functioning. A more complete description of the research program is contained in Salthouse (1992b).

Phase 1

A project described in Salthouse (1993a) focused on the relations between age and performance on the Raven's Progressive Matrices Test. Many previous studies reported substantial age-related declines on this test, and these age relations were confirmed in my laboratory. For example, the correlation between age and the number of correct responses with the standard paper-and-pencil (Advanced) test was −.57 ($n = 221$) in Study 1. A computer administered version of the test in which subjects could take as long as they wanted to work on the problems was used in Study 1 of Salthouse (1994). The correlation between age and the percentage of correct answers in this study was −.39 ($n = 246$).

Because the solution of matrix problems seems to require working memory in order to detect the rules relating matrix elements to one another, it was hypothesized that working memory might function as a mediator of the relations between age and performance in the Raven's test. This hypothesis seemed plausible because previous research revealed substantial negative correlations between age and measures of working memory functioning. For example, two variants of the Daneman and Carpenter (1980) reading span task were used to measure working memory in my laboratory. In five separate studies, each involving over 200 adults from a wide range of ages, the correlations between age and measures of working memory derived from these tasks ranged from −.39 to −.54 (Salthouse, 1991; Salthouse & Babcock, 1991).

These two sets of results—significant relations between age and Raven's performance, and significant relations between age and measures of working memory—are examples of Phase 1 research. That is, although a mediational relation is hypothesized, the discovery that two variables are both related to age does not allow a conclusion that one variable mediates the age-related influences on the other variable. Evidence relevant to that hypothesis must come from Phase 2 research.

Phase 2

Subjects in the first study in the Salthouse (1993a) project performed the Raven's Progressive Matrices Test, and also two working memory tasks. In addition, each of these individuals reported the number of years of formal education completed and made an evaluation of his or her level of health. These latter two variables were included because health and education are often mentioned as possible mediators of age-cognition relations.

An initial analysis of the data from this study revealed that age was associated with a sizable proportion of variance in Raven's performance (i.e., R^2 of .322), but that the age-related variance that was independent of working memory was considerably smaller (i.e., increment in r^2 associated with age after control of working memory of .053). Because the age-related variance was reduced by over 83% when the measure of working memory was statistically controlled, these results suggest that working memory does indeed contribute to the relations between age and Raven's performance.

Figure 6.3 contains a path diagram representing the relations among the variables in this study. Three results should be noted. First, the hypothesized importance of working memory on the relations between age and Raven's performance is supported by the significant coefficients for the paths between age and working memory, and between working memory and Raven's performance. Second, there is no evidence that education contributes to the age differences in Raven's performance because there was no relation between age and education in this sample. And third, self-reported health status does not have a direct influence on performance in the Raven's Test. These latter two results suggest that education and health are probably not important mediators of the relations between age and Raven's performance.

Because of the evidence in this and other studies (e.g., Salthouse, 1992b) that working memory contributes to the relations between age and measures of cognitive functioning, additional studies were designed to attempt to understand the relations between age and working memory. Salthouse and Babcock (1991) hypothesized that working memory could be conceptualized in terms of three components: storage capacity, processing efficiency, and coordination effectiveness. Each hypothesized component was measured in two different tasks based on different versions of the working memory task. For example, the reading span

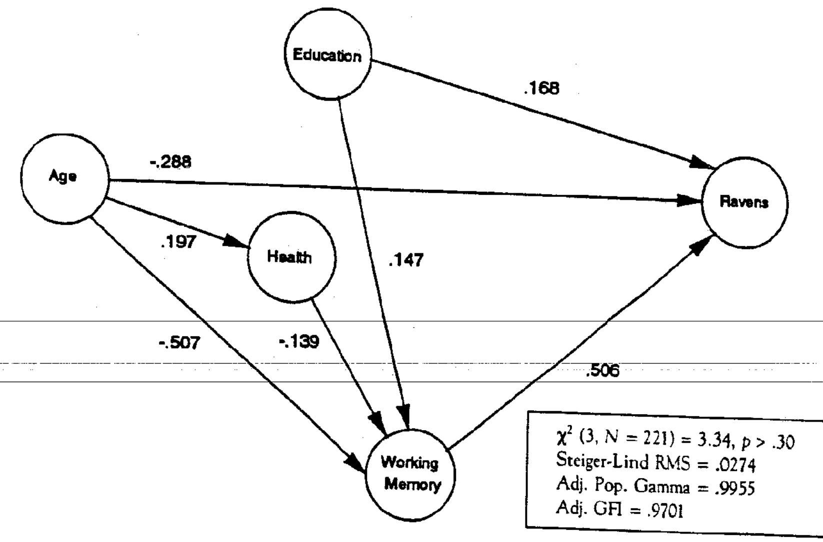

FIG. 6.3. Path diagram illustrating relations among Age, Raven's Progressive Matrices, and three possible mediators (data from Study 1, Salthouse, 1993a).

working memory task required the subject to remember the last word in each sentence while also answering a question about the sentence. The subject's span corresponded to the largest number of sentences for which both the processing (answering sentences) and storage (recalling words) requirements were satisfied on at least two of three trials. A measure of storage capacity was obtained by measuring the subject's word span, a measure of processing efficiency was obtained by measuring the speed with which sentence comprehension questions could be answered, and coordination effectiveness was measured by the speed with which two activities could be performed simultaneously.

A path diagram illustrating the relations among the variables in this study is presented in Fig. 6.4. Notice that the three hypothesized components were all moderately related to one another. However, there was no relation between the measure of coordination effectiveness and working memory functioning. At least as measured in this study, therefore, the coordination efffectiveness component does not appear to be an independent contributor to the age-related differences in working memory.

The fact that a path was needed between age and working memory indicates that there were influences of age on working memory independent of the hypothesized components. A second study was therefore designed to investigate the possibility that a more fundamental common factor might contribute to the relations between age and aspects of working memory. Study 2 in the Salthouse and Babcock (1991) project included measures of processing speed, as represented

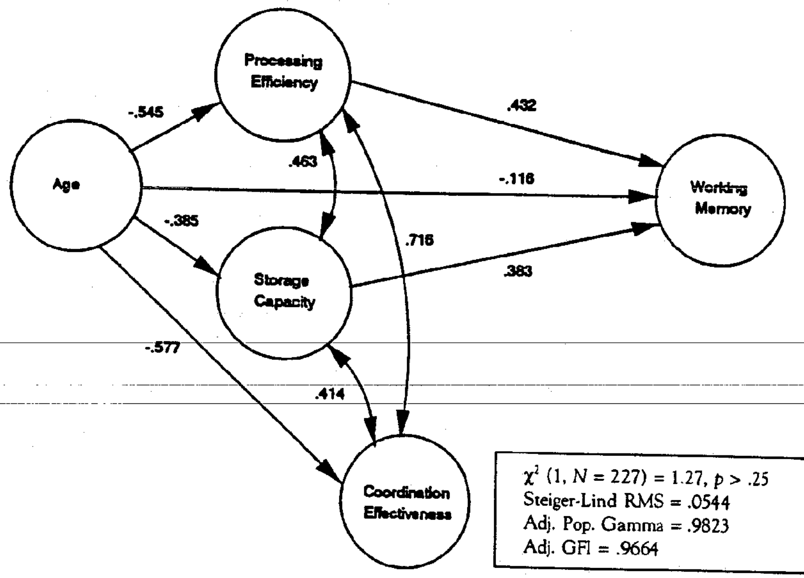

FIG. 6.4. Path diagram illustrating relations among Age, Working Memory, and three hypothesized components of working memory (data from Study 1, Salthouse & Babcock, 1991).

by the speed of making simple perceptual comparisons. Two measures of this construct were added, and the measures of coordination effectiveness dropped.

Relations among the variables in this study are illustrated in the path diagram in Fig. 6.5. The most important result to be noted is that there was no independent influence of age on either working memory, or on the hypothesized components of working memory. It therefore appears that all of the age-related effects on working memory in this particular sample can be accounted for in terms of the influence of processing speed. Other studies using different methods of assessing processing speed and working memory (e.g., Salthouse, 1992b; Salthouse & Coon, 1993; Salthouse & Kersten, 1993) confirmed the large influence of processing speed, although the attenuation of the age-related variance in working memory in these studies was smaller than that in the Salthouse and Babcock (1991) study.

Phase 3

The evidence summarized above is consistent with the hypothesis that processing speed functions as an important mediator of the relations between age and working memory, and probably also of the relations between age and other measures of cognition. The Phase 2 research served a valuable purpose of establishing the relevance of one hypothesized mediator of age-related influences on memory.

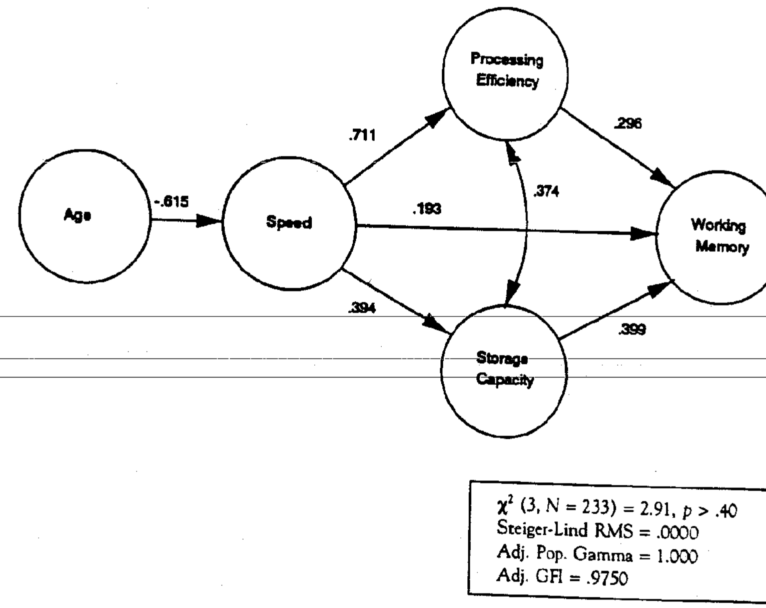

FIG. 6.5. Path diagram illustrating relations among Age, Working Memory, Perceptual Speed, and two hypothesized components of working memory (data from Study 2, Salthouse & Babcock, 1991).

Justification now exists for a focus on explaining why increased age is apparently associated with a slower rate of executing many processing operations, and how slower processing speed contributes to poorer performance in memory and other cognitive tasks.

It seems highly likely that neurophysiological processes are involved in the relations between age and speed. Changes could occur at the level of individual neurons, perhaps because of loss of myelination or a reduction in synaptic transmitters. The number of functional neural cells may also decrease with age, thereby requiring more circuitous pathways for communication. Although numerous plausible mechanisms could be postulated, it is not clear that the alternatives can be discriminated solely on the basis of behavioral measures. Neurophysiological research will therefore probably be required before a definitive conclusion can be reached regarding the processes responsible for relations between age and speed.

A key assumption in the interpretation of relations between speed and cognition is that nearly all cognitive processes require time for their completion, and during that time the information upon which they operate is degrading in either quality or availability. Effectiveness of the processing is greatest when it is more rapid and can be based on the largest amount of accurate information.

Moreover, if the processing is slow, then the amount of simultaneously available information may be reduced, thus impairing higher order cognitive processes dependent on the integration or abstraction of different types of information.

Evidence consistent with the preceding interpretation has accumulated from a variety of sources. For example, the duration of a number of different cognitive processes was found to be slower with increased age (Salthouse & Coon, 1993; Salthouse & Kersten, 1993). Other research found that processing speed has a direct influence on decision accuracy, and not just on study time or decision time (Salthouse, 1994). And finally, examination of different speed measures has revealed that the relations between speed and measures of cognitive functioning are greatest when the speed measures do not simply reflect sensory and motor processes, but also contain a cognitive component such as comparison or substitution (Salthouse, 1993b, 1994).

Neither the mechanisms responsible for the relations between age and speed, nor between speed and cognition, are fully understood at the current time. Nevertheless, the speculations described represent plausible, and most importantly, testable, hypotheses. Furthermore, because the evidence from Phase 2 research indicates that speed does contribute to the relations between age and cognition, one can have confidence that those hypotheses are both relevant and important.

CONCLUSION

I conclude with a brief summary of the major points I attempted to make. I began by describing reasons for the appeal of the notion of processing capacity as an explanatory construct in developmental research. However, because the meaningfulness of any construct is a function of the quality and quantity of relevant evidence, I then discussed three phases of research concerned with investigating the involvement of a hypothesized mediator such as processing capacity in developmental phenomena. Finally, I summarized some of my own research in each of the three proposed research phases focused on the hypothesis that speed or rate of processing functions as a type of processing capacity during adulthood. The processing speed interpretation is still at the speculative stage with respect to mechanisms, but the evidence relevant to the role of processing speed on adult age differences in memory, particularly in what I termed Phase 2 research, suggests that this construct should play a prominent role in any comprehensive explanation of memory development in adulthood.

REFERENCES

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 191–211). New York: Plenum.

Crook, T. H., & Larrabee, G. J. (1990). A self-rating scale for evaluating memory in everyday life. *Psychology and Aging, 5*, 48–57.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450–466.

Dixon, R. A., & Hultsch, D. F. (1983). Metamemory and memory for text relationships in adulthood: A cross-validation study. *Journal of Gerontology, 38*, 689–694.

Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General, 108*, 356–388.

Horn, J. L. (1982). The theory of fluid and crystallized intelligence in relation to concepts of cognitive psychology and aging in adulthood. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 237–278). New York: Plenum.

Hultsch, D. F., Hertzog, C., & Dixon, R. A. (1987). Age differences in metamemory: Resolving the inconsistencies. *Canadian Journal of Psychology, 41*, 193–208.

Light, L. L., & Burke, D. M. (1988). Patterns of language and memory in old age. In L. L. Light & D. M. Burke (Eds.), *Language, memory and aging* (pp. 244–271). New York: Cambridge University Press.

MacCallum, R. C., Wegener, D. T., Uchino, B. N., & Fabrigar, L. R. (1993). The problem of equivalent models in applications of covariance structure analysis. *Psychological Bulletin, 114*, 185–199.

Rushton, J. P., Brainerd, C. J., & Pressley, M. (1983). Behavioral development and construct validity: The principle of aggregation. *Psychological Bulletin, 94*, 18–38.

Salthouse, T. A. (1988a). Resource-reduction interpretations of cognitive aging. *Developmental Review, 8*, 238–272.

Salthouse, T. A. (1988b). The role of processing resources in cognitive aging. In M. L. Howe & C. J. Brainerd (Eds.), *Cognitive development in adulthood* (pp. 185–239). New York: Springer-Verlag.

Salthouse, T. A. (1991). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. *Psychological Science, 2*, 179–183.

Salthouse, T. A. (1992a). Influence of processing speed on adult age differences in working memory. *Acta Psychologica, 79*, 155–170.

Salthouse, T. A. (1992b). *Mechanisms of age-cognition relations in adulthood.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Salthouse, T. A. (1993a). Influence of working memory on adult age differences in matrix reasoning. *British Journal of Psychology, 84*, 171–199.

Salthouse, T. A. (1993b). Speed mediation of adult age differences in cognition. *Developmental Psychology, 29*, 722–738.

Salthouse, T. A. (1994). The nature of the influence of speed on adult age differences in cognition. *Developmental Psychology, 30*, 240–259.

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology, 27*, 763–776.

Salthouse, T. A., & Coon, V. E. (1993). Influence of task-specific processing speed on age differences in memory. *Journal of Gerontology: Psychological Sciences, 48*, P245–P255.

Salthouse, T. A., & Kersten, A. W. (1993). Decomposing adult age differences in symbol arithmetic. *Memory & Cognition, 21*, 699–710.

Sullivan, J. L., & Feldman, S. (1979). *Multiple indicators.* Beverly Hills, CA: Sage.

Webster's Seventh New Collegiate Dictionary (1972). Springfield, MA: Merriam.