In E. Bialystok & F.I.M. Craik (Eds.)
Lifespan Cognition: Mechanisms of Change
NY: Oxford University Press. (2006).

Aging of Thought

Timothy A. Salthouse

Thinking can be defined as the application of reasoning and other cognitive processes to one's available knowledge to achieve some goal. It is therefore useful to begin this chapter by considering the relations between adult age and performance on two activities that involve thinking from this definition. One task is based on the analytical reasoning test formerly used in the Graduate Record Examination to supplement assessments of quantitative and verbal abilities. In this test the examinee reads several statements that establish various constraints, and then evaluates a set of assertions to determine which of them best satisfies those constraints. A very simple problem in this test might consist of the following statements:

> Judy and Elaine want to get together for dinner this week. Judy has to work late on Monday and Tuesday, and is going out with her boyfriend on Friday. Elaine will be out of town on Tuesday and Wednesday. Which days are possible for their dinner—Monday, Tuesday, Wednesday, Thursday, or Friday?

A second activity that can be considered to involve thinking, because it also combines reasoning and knowledge, consists of solving difficult crossword puzzles such as those found in weekend editions of the *New York Times* newspaper. Like the analytical reasoning test, solution of crossword puzzles can be hypothesized to involve reasoning from constraints, although in this case the constraints are the clue: the number of letters in the word, and the identity of any letters that have already been determined from intersecting words.

Because the variables are in different units, in order to allow them to be directly compared they have been converted into standard scores by subtracting the mean from each value and dividing the difference by the standard deviation. The relations of age on the standard scores in these two tasks from four different samples of approximately 200 adults each (i.e., three studies in Hambrick, Salthouse, & Meinz, 1999, and one in Salthouse, 2001) are illustrated in Figure 19.1. It can be seen that the age trends in the two tasks are quite different, with a nearly linear decline across the adult years in analytical reasoning performance, but with older adults achieving the highest average level of performance in the crossword puzzle measure. Because the age trends on these tasks are so different, it is reasonable to ask whether it is meaningful to refer to them both as illustrations of the same phenomenon. In fact, some researchers have argued that the existence of different developmental trends is evidence that the variables represent distinct theoretical constructs (e.g., Horn, 1989; McArdle, Ferrer-Caja, Hamagami, & Woodcock, 2002). However, an alternative perspective, which will be adopted here, is that variables with different age trends could represent a common construct but may differ with respect to the impact of relevant knowledge.

The possibility that at least two different types of age-related influences contribute to performance in cognitive activities has been mentioned since the earliest studies on this topic (e.g., Foster & Taylor, 1920; Jones & Conrad, 1933). Welford (1958) provided a particularly eloquent discussion of the two types of age trends when he referred to one function, which he designated A, as representing organic capacities, and a second function, which he designated B, as representing effects of cumulative experience. He described their developmental trajectories as follows:

> Curve (A) for the organic factors rises to a peak in early adulthood and then declines. Curve (B) for experience rises throughout life. . . . The curve (B) is the integral of (A) on the assumption that it should depend upon cumulative exposure to environmental stimulation, and upon the level of (A) in the sense that this will determine the extent to which environmental stimulation is converted into experience. (p. 13)

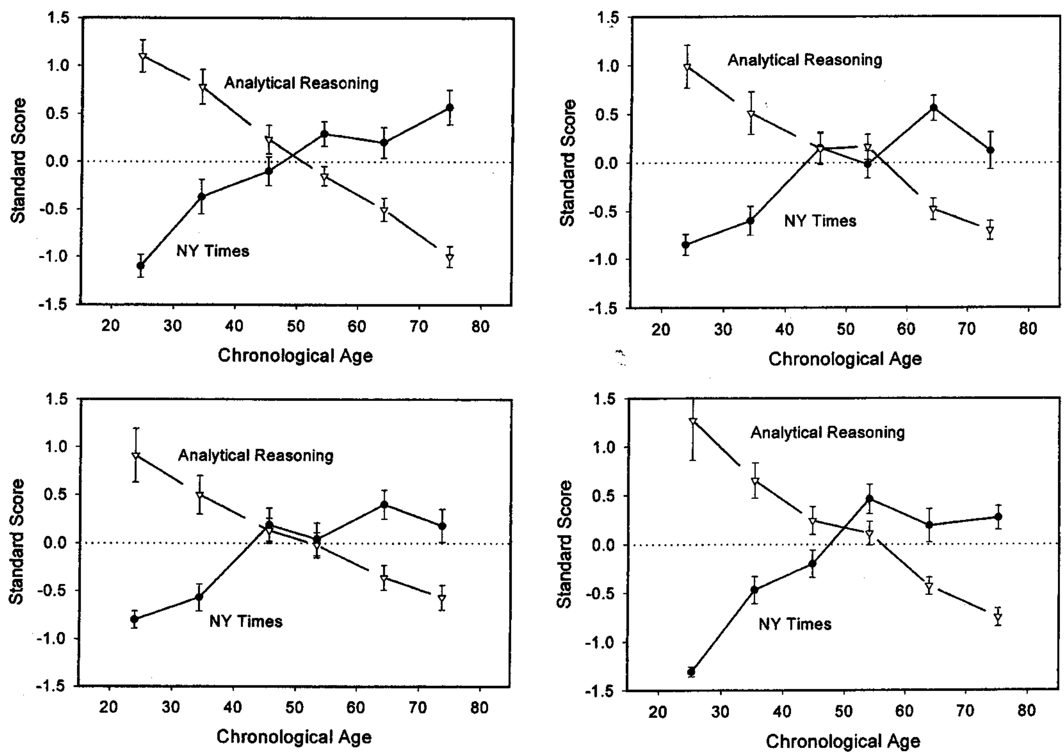

FIGURE 19.1. Relations between age and performance on analytical reasoning and crossword puzzle tasks in studies by Hambrick, Salthouse & Meinz (1999) and Salthouse (2001). Each study involved at least 200 adults with nearly equal numbers at each age between 18 and 80. Bars above and below each point are standard errors.

He went on to suggest that:

> Tasks which make their chief demands upon organic capacities will tend to follow curve (A), those demanding knowledge and experience curve (B). In most cases both types of demand would be made and the result would be intermediate between (A) and (B) according to the balance of demands and the extent to which compensation for deficiencies of organic origin could be made by knowledge gained in the course of experience. (p. 14)

Welford's characterization would probably be readily accepted by most contemporary researchers, but it is surprising how little research is relevant to what he referred to as curve B, or to his hypothesis of knowledge-based compensation. Considerable evidence does exist for the first type of age trajectory mentioned by Welford. Perhaps the most convincing data are those from samples used to establish the norms for standardized cognitive test batteries, such as the Wechsler Abbreviated Scale of Intelligence (WASI, 1999). The matrix reasoning test in this battery involves the examinee inspecting a matrix of geometric figures and patterns, and then attempting to determine the best completion of a section missing from the matrix. In the block design test, the examinee manipulates blocks to produce patterns that will match a target design. Lifespan age trends on these two tasks, with the scores expressed in proportions of the maximum across all ages, are portrayed in Figure 19.2A. It is apparent that these measures of processing efficiency or effectiveness increase dramatically from early childhood until about age 18, after which they decline in a nearly linear manner.

Much less research is consistent with Welford's hypothesized curve B, in which the variable increases continuously from childhood and across most of the adult years. Instead, the majority of the results resemble the patterns illustrated in Figure 19.2B, which are based on the normative data for the WASI Vocabulary and Similarity tests. The Vocabulary test requires the examinee to provide definitions of words, and the Similarities test requires the examinee to state how two words are similar to one another. Inspection of Figure 19.2B reveals that performance in these variables increases dramatically up to about age 50, followed by a gradual decline. Other variables reflecting word knowledge or general information have also revealed a similar curvilinear pattern in adulthood (e.g., Salthouse, 1998, 2003). Furthermore, although there have been many speculations about the role of compensation in adult development (e.g., see Dixon & Backman, 1995), there is still very little empirical evidence documenting the existence of age-related compensation in cognitive activities.

In certain respects, the current chapter can be viewed as an update and extension of Welford's (1958) speculations. The remainder of the chapter is organized as follows. First is a brief summary of the research literature on adult age differences in processing efficiency, or what Welford termed "organic capacities." Next is a discussion of attempts to investigate the relation between processing efficiency and experience-based knowledge in the performance of specific

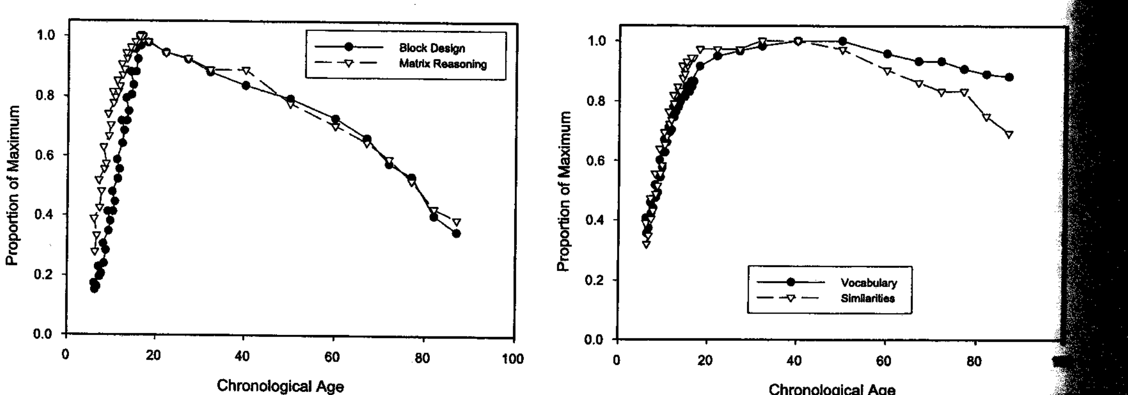

FIGURE 19.2. Proportion of the maximum score as a function of age in four standardized tests. The tests in panel A were designed to have minimal involvement of knowledge while those in panel *B* primarily reflect acquired knowledge. (Data from Table A.1 in WASI, 1999.)

cognitive activities. The final section of the chapter consists of speculations about change mechanisms that might account for age differences in measures of thinking and other aspects of higher order cognition in both the last 75%, and the first 25%, of the human lifespan.

EFFECTS OF AGING ON EFFICIENCY OF BASIC COGNITIVE PROCESSES

A wide variety of tests and tasks have been used to assess efficiency or effectiveness in what Welford (1958, p. 12) referred to as "mental gymnastic" exercises. A key feature of these tests is that they have been designed to minimize the influence of prior experience in an attempt to assess basic abilities or capacities. Many tests included in standardized cognitive test batteries share this characteristic, and because the normative samples are moderately large and selected to be representative of the population, age trends in "organic capacities" can be illustrated with the normative data from these test batteries.

Tests included in four recent cognitive test batteries that can be considered to assess various aspects of thinking are briefly described in Table 19.1. Sixteen different tests are included in the table, with each test involving somewhat different requirements, materials, and procedures (e.g., some had time limits and others did not). In order to express all of the variables in a common scale, the scores have been converted into standard deviation units of a reference group of young adults.

Age trends in these 16 tests are illustrated in the four panels of Figure 19.3. In each case there is a monotonic decline with increased age, such that the average at age 65 is about one standard deviation below the average of the reference group. There is some

TABLE 19.1. Descriptions of tests from standardized cognitive test batteries

Source	*Variable*	*Description*
WAIS III ($N = 2{,}150$)	Digit symbol	Substitute symbols for digits according to a code table as rapidly as possible.
	Block design	Arrange colored blocks to match a design
	Matrix reasoning	Select the alternative that provides the best completion of a missing section of a matrix
	Letter-number sequencing	Listen to an intermixed sequence of letters and numbers and then repeat them back with letters first in alphabetical order and numbers second in numerical order
Woodcock-Johnson III ($N = 2{,}505$)	Visual auditory learning	Learn associations between words and drawings
	Spatial relations	Identify pieces that form a target shape
	Concept formation	Determine the rule that can be used to categorize items
	Visual matching	Speeded identification of matching numbers
Kaufman Adolescent and Adult Intelligence Test ($N = 1{,}350$)	Logical steps	Use logical premises to reach deductions
	Mystery codes	Determine the code (concept) associated with a new pattern
	Memory for block designs	Immediate reproduction of design by manipulation of blocks
	Rebus learning	Learn associations between drawings and words
Delis-Kaplan Executive Function System ($N = 875$)	Tower of Hanoi	Move disks among three towers to convert a starting configuration into a target configuration
	20 questions	Determine the target item from among a set of 30 items with the fewest number of questions
	Card sorting	Identify the basis of cards sorted by the examiner
	Figural fluency	Create as many different line pattern figures as possible in 60 seconds

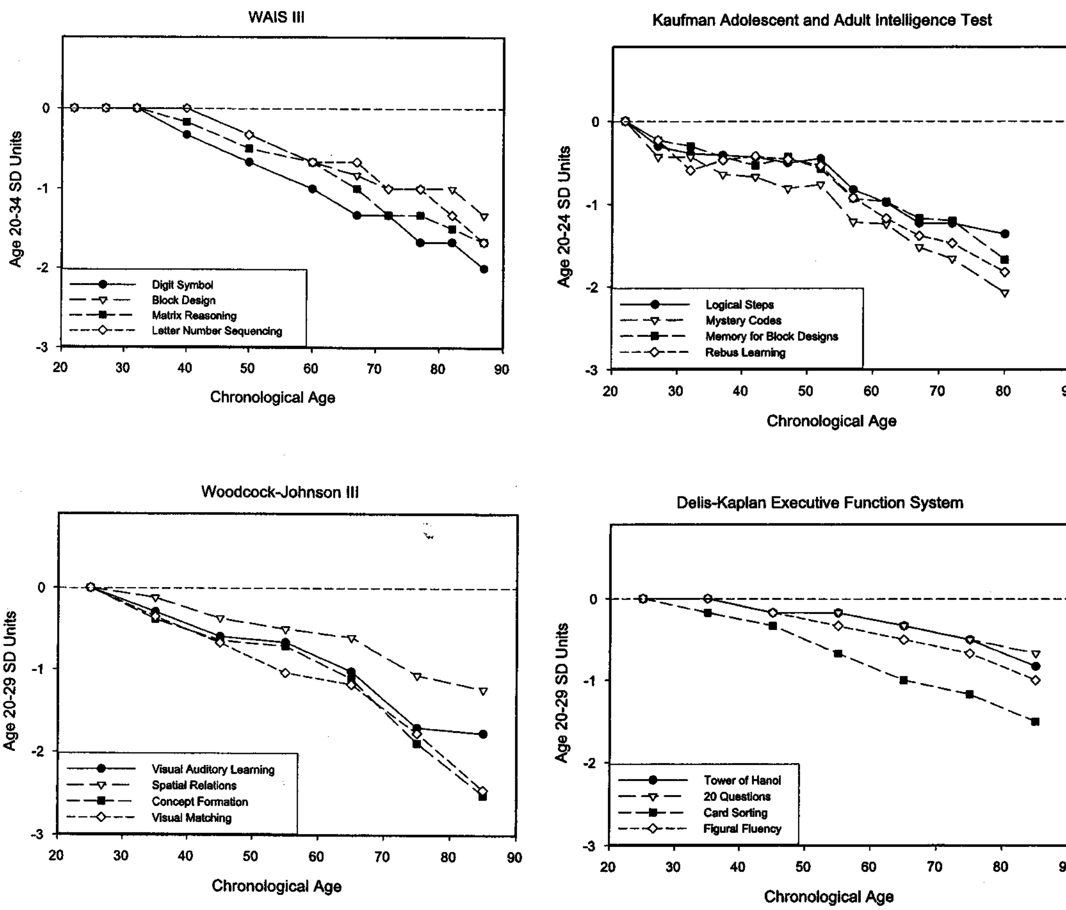

FIGURE 19.3. Performance in tests assessing different aspects of thinking from four standardized test batteries, expressed in units of young adult standard deviation units. Sample sizes are reported in Table 19.1. (Data for this table taken from Table A.1 in Wechsler, 1997; Table A.1 in McGrew & Woodcock, 2001; Table 8.5 in Kaufman & Kaufman, 1993; and Tables H.1, F.1, E.1, and Table C.1 in Delis, Kaplan, & Kramer, 2001.)

variability in the functions, as they appear to be shallower for the four variables in the D-KEFS battery than for the variables in the other batteries. Unfortunately, because different samples of individuals performed the tests in each battery, it is not possible to determine the relative contribution of the tests and of the samples to the apparent differences in age trends.

The data in Figure 19.3 indicate that linear age-related decreases have been observed in a variety of tests that can be postulated to involve thinking. Moreover, it is noteworthy that the pattern was similar across test batteries involving different samples of adults and in variables involving different combinations of materials and procedures. This is an important finding because psychometric tests are often criticized as involving unknown mixtures of theoretical processes, which makes it difficult to determine which particular processes are contributing to any age differences that might be observed. However, when similar age trends are found across a variety of tests involving different combinations of processes it is unlikely that the age-related effects are attributable to one or two critical processes.

Somewhat different patterns of results are occasionally found in studies involving small convenience samples of young and old adults, and with variables of unknown reliability. However, the results most often resemble the patterns in Figure 19.2A and Figure 19.3 when moderately large samples of adults across the entire age range are examined with variables established to have at least moderately high reliability. Results such as these leave little doubt that the average older adult is less nimble than the average young adult in a variety of mental gymnastic exercises.

However, it is important to recognize that all of the tests represented in Table 19.1 and Figure 19.3 were explicitly designed to assess cognitive abilities in the abstract, independent of experience and of any particular context. In fact, abilities assessed by these types of tests have been characterized as determining the level of performance that can be achieved when one doesn't know what to do and has no relevant experience. Because this is seldom the case in situations outside the laboratory, assessments such as those represented in Figure 19.3 reflect only a limited perspective on adult thinking.

INVESTIGATING RELATIONS BETWEEN PROCESSING EFFICIENCY AND KNOWLEDGE

In part because many leadership positions in business and government are occupied by older adults, it is often assumed that increased age confers advantages in activities requiring complex thought and decision making. Factors related to seniority may play a role in the high prevalence of older adults in many leadership positions, but it is also possible that increased age is associated with higher levels of knowledge or skills that have been difficult to document in the laboratory. In fact, there have been many suggestions that compared to young adults, older adults rely more on wisdom or accumulated knowledge to compensate for any deficiencies that may be evident in basic abilities. An early statement of this position was the claim by Jones and Conrad (1933) that "much of the effective power of the adult . . . is evidently derived from accumulated stocks of information" (p. 254).

Although seemingly obvious and probably widely accepted, the idea that increased age is associated with greater knowledge and experience that may serve to compensate for age-related declines in basic cognitive abilities has been difficult to investigate for at least three reasons. First, almost by definition, people with very high levels of experience and knowledge are rare, and it is possible that results based on small samples of elite individuals might not be typical of what would be found in the general population. Second, many cognitive activities that are dependent upon knowledge, such as making decisions about finances, medical treatments, or consumer purchases, are quite complex, and sometimes it is not even possible to specify the optimum level of performance in these activities because it depends on characteristics of the individual such as his or her personality (e.g., preference for risk-taking, tolerance for uncertainty), values, and goals. And third, the influence of knowledge on performance has not been rigorously examined because of the difficulty of assessing the quality and quantity of an individual's relevant knowledge.

How can the relative contributions of processing efficiency and knowledge be investigated in the face of these difficulties? One strategy is to begin with relatively simple tasks in which: (1) there are large populations of potential participants; (2) the tasks have objectively correct solutions or answers; and (3) it is possible to assess the quantity of potentially relevant knowledge in each individual. The primary prediction under these conditions is that to the extent that both processing efficiency and knowledge contribute to successful performance, then statistical control of a measure of knowledge should increase the relative influence of processing efficiency and result in more negative relations between age and task performance. Data from studies reported in Hambrick et al. (1999) can be used to examine this prediction because the participants in these studies performed a variety of simple verbal tasks and also completed tests of vocabulary that assessed relevant knowledge. Among the tasks in these studies were anagrams, make words, and word switch. In the anagrams task the examinee was to identify specific target words that could be created by rearranging a set of letters, and in the make words task the goal was to create as many different words as possible from a specified set of letters. The word switch task required the participant to identify the fewest number of intermediate words needed to convert one word into another, with each intermediate word involving a change of only one letter from the previous word. As an example, if the initial word was *foot* and the final word was *head*, then one possible solution would involve the following sequence of words: *foot-food-hood-hold-held-head*.

Each of these tasks can be considered to require thinking because successful performance requires the application of cognitive operations to one's knowledge. However, with none of these variables was the correlations with age significantly different from zero. That is, the age correlations were -.02 ($N = 402$) with anagram performance, .03 ($N = 202$) with make words performance, and -.03 ($N = 202$) with word switch performance. As expected, each variable was positively correlated with an index of relevant knowledge in the form of scores on tests of vocabulary (i.e., correlations ranging from .36 to .58), and increased age was associated with higher vocabulary scores (i.e., correlations ranging from .15 to .39). Moreover, when the variance in the vocabulary variable was statistically controlled with a partial correlation procedure, all of the age correlations became significantly negative (i.e., $p < .01$). Specifically, after partialling the vocabulary score the age correlations for anagrams, make words, and word switch were, respectively, -.17, -.22, and -.25.

This pattern of results suggests that, at least in these samples and with these particular tasks, greater knowledge on the part of older adults appears to offset the negative age relations in processing efficiency such that there was no relation of age to overall performance. That is, these statistical control results imply that increased age would have been associated with substantially lower levels of performance if relevant knowledge had not been positively related to age. A further implication of these findings is that under the right circumstances greater knowledge may not only eliminate age differences but could even reverse them. The combination of adults recruited on the basis of experience working crossword puzzles and a measure of the number of words answered correctly in solving difficult crossword puzzles may be one such combination of circumstances because the results in Figure 19.1 indicate that there were positive relations between age and crossword puzzle performance (i.e., the age correlations in the four studies ranged from .31 to .46).

The results just described suggest that when knowledge is relevant to the task, and when the amount is greater with increased age, age differences in measures of thinking performance are either reduced, eliminated, or reversed. However, the possession of a larger amount of knowledge does not necessarily mean that it is relied upon to a greater extent in the performance of cognitive activities. A key question regarding the role of knowledge in thinking is, therefore, whether increased age is merely associated with a greater quantity of knowledge or whether it is also associated with a greater dependence on that knowledge.

Salthouse (1993; also see 2003) attempted to investigate this question by computing regression equations relating performance on several target tasks to measures of speed (perceptual comparison scores) and knowledge (vocabulary scores). For the purpose of these analyses, speed was viewed as an indicator of processing efficiency, or what Welford (1958) termed "organic capacities," and vocabulary was viewed as an indicator of the effects of cumulative experience. The target tasks in this project were simple verbal tasks such as letter fluency, anagrams, make words, and so on.

The analytical method involved constructing separate regression equations for the samples of young and old adults of the form:

$$\text{Performance} = b1(\text{Processing Efficiency}) + b2(\text{Knowledge}).$$

The major issue was whether, in addition to differences in the level of the predictors, there were age differences in the b parameters representing the weighting of the predictors on performance. That is, based on earlier research, young adults were expected to have a higher average level of processing efficiency and older adults were expected to have a higher level of relevant knowledge. Of particular interest, however, was whether the groups also differed in their regression weights, with older adults having smaller values of the $b1$ parameter and larger values of the $b2$ parameter than young adults. A finding of this type could be interpreted as evidence of compensation in the sense that increased age was associated with greater reliance on one's strengths and reduced reliance on one's weaknesses.

The same analytical method was applied in two studies, with each study consisting of separate samples of young and old adults and involving somewhat different criterion tasks. The results in both studies indicated that the two groups differed in the expected directions with respect to the level of the processing efficiency and knowledge variables and that both processing efficiency and knowledge were important in predicting performance in the criterion tasks (i.e., the $b1$ and $b2$ parameters were both significantly different from 0 with each task in each sample). However, the magnitudes of those influences were nearly the same for young and old adults (i.e., there were no age differences in the values of the $b1$ or $b2$ parameters). This pattern of results indicates that although young adults had a higher average level of processing efficiency, and old adults had a higher average level of knowledge, the regression weights, representing the degree to which performance in the criterion task varied with a given amount of change in each predictor variable, were similar in the two groups. It therefore appears that young and old adults achieved similar performance in these simple verbal tasks because of differences in the levels of the relevant factors, and not because of a different pattern of reliance on those factors.

This regression-based analytical approach is promising because it has the potential to provide quantitative estimates of the contributions of different factors to level of performance in adults of different ages, and it also allows investigation of the possibility that reliance upon those factors differs as a function of age. However, a limitation of the analyses reported by Salthouse (1993) is that only one value of processing efficiency and one value of relevant knowledge were available for each person, and thus the analyses had to be conducted at the level of groups instead of the level of individuals. It would be desirable to extend this type of analysis to allow estimates of the level and the weighting of predictors for each individual, and to apply the analyses to more complex tasks involving different types of relevant knowledge and other measures of processing efficiency.

AN ANALOGY TO ATHLETICS?

From the current perspective the effects of aging on thinking can be considered somewhat analogous to the effects of aging on the proficiency of a professional athlete. That is, beginning in their 20s most athletes probably experience a gradual decline in many physical abilities, but there may be increases in aspects of their relevant knowledge (e.g., declarative, or *what* information; procedural, or *how* information; and conditional, or *when* information). Furthermore, it is possible that the relation between knowledge and physical ability changes with age, perhaps in the direction of better awareness of when and how particular actions should be performed. However, at some point the increased level of knowledge may no longer offset the decreased level of physical ability, at which time the athlete probably ceases to be competitive at the highest level.

The thinking/athlete analogy is also meaningful because it may help explain why predictions from measures of performance on abstract tests to competence in activities outside the laboratory have frequently been low. That is, there may be only a modest relation between performance in one's sport and the level of physical abilities assessed by speed of running a fixed distance, amount of weight that can be lifted, distance a ball can be thrown or kicked, and so on, because the latter do not reflect the knowledge one has acquired about his or her sport. For the same reasons, a weak relation might also be expected between performance on cognitive exercises in the laboratory and level of functioning in daily activities because of the failure to take relevant knowledge into consideration.

Although there are some intriguing parallels, the analogy between thinking and the skills of an elite athlete should not be carried too far because knowledge is likely to be much more important in most mental activities than in physical activities. At the very least this could mean that the point at which greater knowledge no longer offsets declines in "organic capacities" occurs later in life, and it may also mean that level of performance could continue to increase throughout adulthood in activities that are highly dependent on knowledge.

CHANGE MECHANISMS

How can the effects of aging in adulthood (or of development in childhood) on thinking be explained from the perspective described above? The preceding discussion implies that two, and possibly three, distinct types of change mechanisms will be needed. Although the discussion focused on research in aging, it seems likely that similar change mechanisms will be required to account for phenomena in cognitive development. First, there is a need to explain what is responsible for age-related decreases (or increases in childhood) in the efficiency of many cognitive processes. Second, there is a need to explain what is responsible for age-related increases in the accumulation and maintenance of knowledge. And third, depending on the outcome of relevant research, there may also be a need to explain what is responsible for any changes found in how processing efficiency and knowledge are combined in the performance of specific cognitive activities.

Because the age trends apparent in Figures 19.2A and 19.3 can be presumed to be attributable to changes in the efficiency of processing, explanations are needed to account for improvements and declines in the effectiveness of these mental gymnastics exercises. However, before evaluating particular proposals, three meta-issues concerned with possible mechanisms and the manner in which they might be most productively investigated should be considered. The issues are meta in nature because they are likely to affect the nature and scope of any specific hypotheses that might be proposed.

One of these issues is whether the focus of the explanation is on a single variable or on multiple variables. Most cognitive variables are positively correlated with one another, and thus it is important to determine the extent to which the age-related influences on a particular variable are unique to that variable and statistically independent of age-related influences on other variables. When only one variable is considered in isolation, it is impossible to investigate relations of that variable to other variables or to examine age-related effects on that variable in the context of age-related effects on other variables. Furthermore, a multivariate focus is necessary to determine the most meaningful grouping or organization of variables for the interpretation of age-related influences, which is the kind of information that would be relevant to the question of the degree to which the cognitive system is modular with respect to age-related influences (see Chapter 18, this volume).

A second meta issue is whether the proposed change mechanisms are hypothesized to operate at the same level as the phenomena to be explained, or whether they are postulated to operate at a lower, more reductionistic level. Many of the currently popular interpretations of individual differences in cognitive functioning are based on the assumption that certain cognitive constructs are more fundamental or primitive than others in the sense that changes in these constructs precipitate changes in other constructs. Among the constructs that have been hypothesized to possess this privileged status are aspects of attention such as inhibitory efficiency, executive functioning, working memory, and processing speed. An advantage of explanatory constructs at the same level of analysis as the to-be-explained phenomena is that it is possible to identify plausible mechanisms, such as how the amount of information that can be maintained in working memory could affect performance on many different types of cognitive tasks. However, two limitations of interpretations at the same level of analysis are that an explanation would still be needed to account for changes in the hypothesized primitive construct (e.g., why are there age-related changes in working memory?), and it is difficult to establish causal priority when both the cause and effect constructs are operationalized in terms of similar types of observable behavioral variables.

Interpretations in which the hypothesized causal construct is at a different level of analysis than the to-be-explained construct, such as when it is operationalized with a measure of neurobiological structure or function, have a different pattern of strengths and weaknesses. For example, it may be more difficult to specify the mechanism by which a neurobiological characteristic such as synaptic density, quantity of a particular type of neurotransmitter, or intactness of myelin contributes to different levels of performance on a cognitive test, but because these types of neurobiological characteristics are unlikely to be affected by level of cognitive performance, there may be less ambiguity about the causal direction between the constructs.

The third meta issue relevant to evaluating possible interpretations of age-related changes in processing efficiency is whether the relevant comparisons are based on static or dynamic information. Many of the speculations about change mechanisms in both aging and child development are based on relatively static cross-sectional information, but strong conclusions about mechanisms of change will require longitudinal information. Moreover, because information on concurrent or correlated change in two or more variables is ambiguous about causal priority, the most informative patterns for investigating change mechanisms will likely be lead-lag relations in which changes in the hypothesized causal construct precede changes in the hypothesized consequence construct.

A large number of specific hypotheses have been proposed, and many more could be proposed, to account for changes in processing efficiency in the period of child development and across the adult years. However, the meta issues just discussed appear so fundamental that they need to be considered before attempting to evaluate the plausibility, or even the applicability, of any specific hypotheses.

Knowledge

As noted earlier, most of the results from large representative samples indicate that performance on various tests of knowledge increases only to about age 50, after which it either remains stable or declines. An initial question concerned with age-related change in knowledge, therefore, is why knowledge does not continue to increase with increased age. Several hypotheses were discussed by Salthouse (2003), including the possibilities that exposure to new sources of information may decrease with age and that forgetting of old information might offset the acquisition of new information. Perhaps the most plausible interpretation of the failure to find continuous increases in knowledge across adulthood is that most standardized tests have been designed to assess general, culturally shared knowledge, and not the personal idiosyncratic knowledge that is acquired as an individual develops his or her unique vocational and avocational interests. Unfortunately, because assessments of idiosyncratic knowledge are not yet available, there is currently little evidence relevant to this interpretation.

Another issue with respect to change in knowledge is whether experience is merely necessary, or is also sufficient, for the acquisition of knowledge. That is, when other factors are equal, is mere exposure (which throughout life will tend to be positively correlated with age) sufficient to account for increased knowledge, or are deliberate or conscious efforts at acquisition (which might increase in efficiency across the period of child development and decrease in efficiency across the adult years) necessary? Other questions that will need to be answered before one can claim to understand age-related changes in knowledge are the role of quantity and quality of existing knowledge, frequency and variety of exposure to new information, and level of processing efficiency on the acquisition and maintenance of knowledge.

Dependence on Knowledge

If future research reveals evidence of age-related differences in the reliance on knowledge during the performance of cognitive activities, then an explanation will also be needed to account for those changes. However, because very little research has been reported on this topic, it is still an open question whether change mechanisms are needed to account for differences of this type.

Five models for the role of knowledge on cognitive performance across adulthood were recently described by Salthouse (2003). Four of the models assume additive effects of knowledge and age, and differ with respect to the direction of the relations between age and knowledge, and between age and ability. Because the two sets of relations were assumed to combine in an additive fashion, from the perspective of these models explanations would only be needed to account for age-related effects on basic abilities and on knowledge. However, the fifth model discussed by Salthouse (2003) was a moderation model that postulates that knowledge alters the relations between age and cognitive performance in the direction of greater positive effects of knowledge at older ages. Only if the data were found to be consistent with this type of model would an explanation necessarily be required to account for age-related changes in the relation between knowledge and cognitive performance.

Given the paucity of relevant information at the current time, a high priority for research in both the child and adult portions of the lifespan is information on how knowledge contributes to cognitive functioning and whether the relation between knowledge and cognitive performance varies as a function of age. However, rather than relying exclusively on speculation as has largely been the case in the past, analytical methods should be used that allow rigorous empirical investigation. This will likely require explicit operational definitions of key constructs and articulating the hypothesized relations in enough detail to allow sensitive evaluations of their plausibility.

SUMMARY

Adult age differences, and developmental differences in childhood, have been clearly documented in measures of what are often assumed to reflect the efficiency of basic cognitive processing. There is also considerable evidence of (nonlinear) positive relations between age and amount of general, culturally shared, knowledge, although little is known about the relation of age to one's total knowledge, which includes the difficult-to-measure knowledge that is idiosyncratic to a particular individual. Unfortunately because there have been few investigations of the role of knowledge in specific activities that require thinking, it is difficult to reach strong conclusions at the current time concerning effects of development or aging on quality or effectiveness of thinking. Some research has indicated how greater knowledge might allow high levels of functioning to be achieved by older adults despite lower levels of processing efficiency, but it has thus far been limited to a few, very simple, tasks, and there is apparently no comparable research with children.

With respect to change mechanisms, at least two distinct age-related influences need to be explained:

negative effects on processing efficiency (positive across the childhood years) and positive effects on knowledge. However, a third age-related influence may also need to be explained if future research were to indicate that the relation between task performance and either processing efficiency or knowledge differs as a function of age.

Finally, it is important to note that a major weakness of the contemporary literature in aging and cognition, and likely also in the literature on cognitive development, is very limited understanding of the relations between age and knowledge, and of the impact of relevant knowledge on functioning in cognitively demanding activities inside and outside of the psychological laboratory. Because most of our cognitive activities are based at least in part on what we know and what we have done in the past, any conclusions about the effects of development or aging on the efficiency or effectiveness of thinking must remain tentative until more is known about the role of knowledge in the cognitive functioning of adults (and children).

References

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System*. New York: Psychological Corporation.

Dixon, R. A., & Backman, L. (1995). *Psychological compensation: Managing losses and promoting gains*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Foster, J. C., & Taylor, G. A. (1920). The applicability of mental tests to persons over 50. *Journal of Applied Psychology, 4*, 39–58.

Hambrick, D. Z., Salthouse, T. A., & Meinz, E. J. (1999). Predictors of crossword puzzle proficiency and moderators of age-cognition relations. *Journal of Experimental Psychology: General, 128*, 131–164.

Horn, J. L. (1989). Models of intelligence. In R. L. Linn (Ed.), *Intelligence: Measurement, theory, and public policy* (pp. 28–73). Urbana: University of Illinois Press.

Jones, H. E., & Conrad, H. (1933). The growth and decline of intelligence: A study of a homogeneous group between the ages of ten and sixty. *Genetic Psychological Monographs, 13*, 223–298.

Kaufman, A. S., & Kaufman, N. L. (1993). *Kaufman Adolescent and Adult Intelligence Test (KAIT)*. Circle Pines, MN: American Guidance Service.

McArdle, J. J., Ferrer-Caja, E., Hamagami, F., & Woodcock, R. W. (2002). Comparative longitudinal structural analyses of growth and decline of multiple intellectual abilities over the life span. *Developmental Psychology, 38*, 115–142.

McGrew, K. S., & Woodcock, R.W. (2001). *Woodcock-Johnson III technical manual*. Itasca, IL: Riverside Publishing Company.

Salthouse, T. A. (1993). Speed and knowledge as determinants of adult age differences in verbal tasks. *Journal of Gerontology: Psychological Sciences, 48*, P29–P36.

Salthouse, T.A. (1998). Independence of age-related influences on cognitive abilities across the life span. *Developmental Psychology, 34*, 851–864.

Salthouse, T.A. (2001). Structural models of the relations between age and measures of cognitive functioning. *Intelligence, 29*, 93–115.

Salthouse, T.A. (2003). Interrelations of aging, knowledge, and cognitive performance. In U. Staudinger & U. Lindenberger (Eds.), *Understanding human development: Dialogues with lifespan psychology* (pp. 265–287). Dordrecht, Netherlands: Kluwer Academic Publishers.

WASI: Wechsler Abbreviated Scale of Intelligence. (1999). San Antonio, TX: Psychological Corporation.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale – Third Edition*. San Antonio, TX: Psychological Corporation.

Welford, A. T. (1958). *Ageing and human skill*. London: Oxford University Press.