The Course of Adult Intellectual Development

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A program of research is summarized that represents the author's lifelong efforts to understand the adult life course of intellectual abilities. The Seattle Longitudinal Study has assessed mental abilities in more than 5,000 adults and has followed some for as long as 35 years. Integrative findings are provided on patterns and magnitudes of age changes, cohort differences, factor structure of mental abilities, antecedents for individual differences in aging trajectories, and interventions designed to remediate cognitive aging effects.

This article presents a relatively brief and integrative account of my lifelong efforts to gain an understanding of the basis for the vast individual variations in the life course of adult intellectual abilities. This work has been done within the context of the Seattle Longitudinal Study (SLS), which began as my doctoral dissertation at the University of Washington in 1956 and the sixth cycle of which was completed in 1992. The theoretical basis for my work on adult intellectual development was provided by Thurstone's (1938) conceptualization of psychometric intelligence. This influence was transmitted to me by my undergraduate mentor, Read Tuddenham, and one of my graduate teachers, Paul Horst. My graduate training in clinical psychology and the influence of my dissertation advisor, Charles Strother, are reflected in a continuing emphasis on the role of individual differences and the influence of sociocultural antecedents on ability functioning.

At an early stage of my career, I was confronted with addressing the discrepancies between cross-sectional and longitudinal findings in the study of adult intellectual development. I soon became convinced that this issue needed to be addressed by following over time a structured cross-sectional sample, such as the one I had collected for my dissertation. As a consequence, I designed a follow-up study that was put into the field in 1963 and provided some answers, but also raised sufficient methodological and substantive questions to demand a continuing program of research (including six major and several collateral data collections) that is still in progress.

Findings resulting from my previous efforts have been widely disseminated in the psychological and gerontological literature. A comprehensive report through Wave 4 of the study may be found in Schaie (1983). That report has been updated by various analyses of the Waves 5 and 6 data (e.g., Schaie, 1989a, 1990a, 1993a, 1993b; Schaie & Hertzog, 1986; Schaie, Plomin, Willis, Gruber-Baldini, & Dutta, 1992; Schaie et al., 1993; Schaie & Willis, 1993, Willis, 1989). I also refer the reader to a forthcoming monograph (Schaie, in press), which provides more complete data on the entire set of studies. Anyone who studies behavioral change over age or time has to come to grips with understanding the relationship between cross-sectional and longitudinal data sets (the age–cohort–period problem). Thus, the course of this work has involved the dialectic interplay of substantive data collections that occasionally required the development of new methods or the reinterpretation of established methodologies (cf. Schaie, 1965, 1973, 1977, 1986, 1988). Here, I provide an integrative overview of both previously published work and the most recently acquired data for those less familiar with this work.

The Seattle Longitudinal Study

The principal data base for this study consists of more than 5,000 subjects, on whom cognitive and other collateral data were acquired during our six major testing cycles (1956, 1963, 1970, 1977, 1984, 1991; see Figure 1). In addition, there were four related studies dealing with the effects of life complexity, shifting our sampling procedures from sampling without replacement to sampling with replacement, the "aging" of the test battery,

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Author's note. The kind of life-long program of research summarized here must depend greatly on many contributions by colleagues and students too numerous to list. However, I wish to acknowledge my particular gratitude for the seminal contributions of my wife and colleague, Sherry L. Willis; to my mentors Read D. Tuddenham, Paul Horst, and Charles R. Strother; and to my colleagues and one-time students, Paul B. Baltes, Theresa M. Cooney, Ranjana Dutta, Kathy Gribbin, Ann Gruber-Baldini, Christopher Hertzog, Gisela Labouvie-Vief, Ann O'Hanlon, Scott B. Maitland, and Iris A. Parham. I am also greatly indebted for the enthusiastic support of members and staff of the Group Health Cooperative of Puget Sound. An earlier, limited portion of this overview, without the inclusion of our most recent data, appeared in Schaie (1993a). In addition to the cited research literature, extensive documentation of the data reviewed here will be found in a forthcoming monograph (Schaie, in press).

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Figure 1
Design of the Seattle Longitudinal Study

Study Waves					
1956	1963	1970	1977	1984	1991
S_1T_1 (N = 500)	S_1T_2 (N = 303)	S_1T_3 (N = 162)	S_1T_4 (N = 130)	S_1T_5 (N = 92)	S_1T_6 (N = 71)
	S_2T_2 (N = 997)	S_2T_3 (N = 420)	S_2T_4 (N = 337)	S_2T_5 (N = 204)	S_2T_6 (N = 161)
		S_3T_3 (N = 705)	S_3T_4 (N = 340)	S_3T_5 (N = 225)	S_3T_6 (N = 175)
			S_4T_4 (N = 612)	S_4T_5 (N = 294)	S_4T_6 (N = 201)
				S_5T_5 (N = 628)	S_5T_6 (N = 428)
					S_6T_6 (N =690)

S = Sample; T = Time of Measurement

and cognitive similarity within biologically related persons (family study) . All of our study participants are or were members of an HMO (Group Health Cooperative of Puget Sound) in the Seattle, Washington, metropolitan area, or family members of these individuals. This HMO has a large, individually recruited membership that includes independent crafts people, service occupations, and all levels of professionals; also, it serves as health care provider for governmental subdivisions and labor unions that include both blue-collar and white-collar employees. Although our sample underrepresents the lowest socioeconomic segment of the population, it is quite representative of at least the upper 75% range of the socioeconomic spectrum. This kind of broad population representation is rare in most studies of psychological individual difference variables.

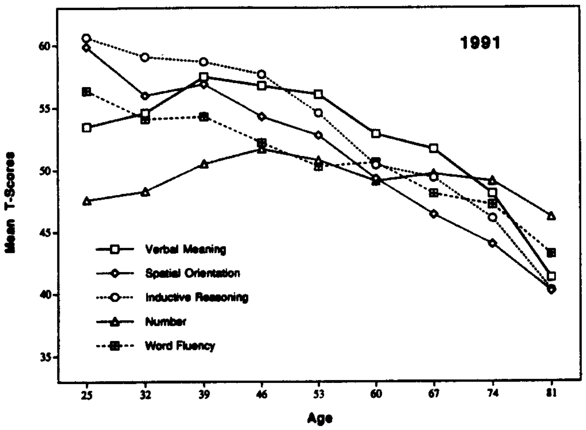
Similar to other longitudinal studies, we have encountered nonrandom dropout effects; that is, those who return for retest, on average, tend to outperform those who do not return. These dropout effects are of greater magnitude subsequent to the first retest occasion, and they are not systematically related to age. However, the reasons for dropout do change across the age span. Attrition effects have been reported for each of our study cycles, and we have proposed corrections that adjust for the effects of attrition and other confounds on estimates of cognitive age changes (e.g., Baltes, Schaie, & Nardi, 1971; Cooney, Schaie, & Willis, 1988; Schaie, 1988; Schaie, Labouvie, & Barrett, 1973).

The core battery used throughout our study has assessed the primary mental abilities of verbal meaning, space, reasoning, number, and word fluency, identified by Thurstone (1938) as accounting for the major share of individual differences in cognitive abilities in children and adolescents. Also assessed consistently have been the dimensions of rigidity–flexibility (Schaie, Dutta, & Willis, 1991; Schaie & Parham, 1975; Schaie & Willis, 1991). Some limited demographic data were collected during the first three cycles. These have been supplemented since 1974 by a more complete personal data inventory, the Life Complexity Inventory (LCI; Gribbin, Schaie, & Parham, 1980), that includes topics such as major work circumstances (with homemaking defined as a job), friends and social interactions, daily activities, travel experiences, physical environment, and lifelong educational pursuits. To be able to explore age changes and age differences in factor structure, we expanded the original core battery to include multiple markers for most abilities beginning with the fifth (1984) cycle. Additional markers were obtained from either the Educational Testing Service's kit of factor–reference tests (Ekstrom, French, Harman, & Derman, 1976), or from the Adult Development and Enrichment Project (ADEPT; Blieszner, Willis, & Baltes, 1981), or from specially constructed alternate forms (Schaie, 1985; Zelinski, Gilewski, & Schaie, 1993). The primary abilities of verbal comprehension, spatial orientation, inductive reasoning, numeric ability, and perceptual speed are now measured at the latent construct level (cf. Schaie et al., 1991; Schaie, Willis, Hertzog, & Schulenberg, 1987; Schaie, Willis, Jay, & Chipuer, 1989). Certain measures of verbal memory, a criterion measure of "real life tasks," the Basic Skills Assessment Test: Reading (Educational Testing Service, 1977), and a scale for measuring participants' subjective assessment of ability changes between test cycles (Schaie, Willis, & O'Hanlon, in press) have also been added. Health history records were obtained for those subjects who were followed for at least 14 years. Each outpatient visit or hospital day was coded by diagnosis and annual illness counts were constructed by summing illness incidents and illness episodes (Gruber-Baldini, 1991; Hertzog, Schaie, & Gribbin, 1978).

Integrative Summary of Results From the Seattle Longitudinal Study

My inquiries have generally focused on six major questions, which I have attempted to ask with increasingly greater clarity and more sophisticated methodologies at each successive stage of the study (cf. Schaie, 1965, 1977, 1988). First, I wanted to know whether intelligence changes uniformly through adulthood or whether there were different life-course ability patterns. Second, it seemed important to discover at what age reliably detectable age decrements in ability occurred and to determine the magnitude of that decrement. Third, I was intrigued by the possibility of demographic shifts in intellectual performance; hence, I wished to investigate patterns of generational (cohort) differences in intellectual abilities as well as their magnitude. Fourth, I was concerned with the stability of the factor structure of the psychometric abilities across the adult life course. Fifth, I wished to determine what accounts for the vast individual differences in age-related change in adulthood. And, finally, influenced by the work of my wife and colleague, Sherry L. Willis, I questioned whether intellectual decline with increasing age can be reversed by educational

Figure 2
Cross-Sectional Mean T Scores for Single Markers of the Primary Mental Abilities



Note. 1991 data.

interventions. I review these questions and try to provide an integrative report on what we have learned from the SLS to provide answers.

Differences in Life-Course Ability Patterns

At the beginning of my inquiries, the then-scientific wisdom argued that psychological constructs should be measured with the best single marker for that construct. More recently, we have come to believe that it is better to measure inferred constructs by multiple markers. Given the length of these studies, I have more data on single than on multiple markers but will describe our findings at both levels.

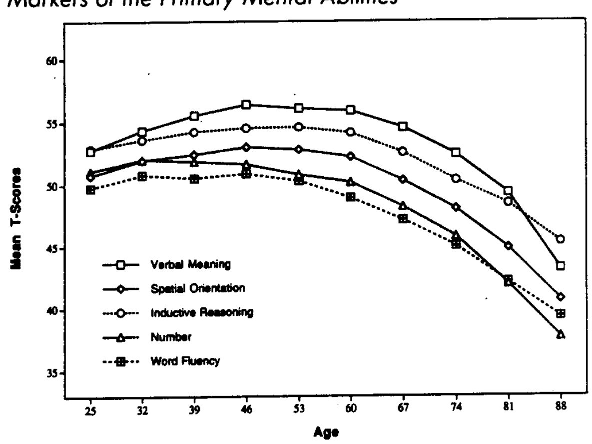
Single ability markers. We have clearly shown that there is no uniform pattern of age-related changes in adulthood across all intellectual abilities. Hence, an overall index of intellectual ability (IQ) does not suffice if one wishes to understand age changes and age differences in intellectual functioning for either individuals or groups. This is the case whether age differences (cross-sectional data) or age changes (longitudinal data) are considered. To document this fact, Figure 2 shows cross-sectional patterns for the five abilities that have been examined throughout the entire study for the last (1991) study wave. The cross-sectional data simply involve a comparison of the directly observed standardized mean scores for all of the different seven-year age groups assessed during our last data collection. The cross-sectional data show two different patterns: (a) Three of the abilities peak in young adulthood and show linearly accelerating age differences that are steepest for spatial orientation and inductive reasoning, but are less pronounced for word fluency; and (b) verbal meaning and number peak in midlife. However, verbal meaning, a somewhat speeded test, begins to show negative age differences by early old age, whereas number has an almost level age-differences profile through adulthood.

Going beyond the between-group findings that confound age and differential experience, Figure 3 shows longitudinal gradients that were obtained by averaging, for each age segment, all of the within-subject data for those individuals who had been followed for the seven years bracketed by that age segment. In other words, each segment involves a longitudinal follow-up, but successive segments are on different individuals. Sufficient data were available to follow this procedure over the age range from mean age 25 to mean age 88. The seven-year age changes were then cumulated, and the longitudinal gradients were centered on the observed mean for the 53-year-old group (our average subject age) in 1991.

The longitudinal gradients show at least modest gain for all abilities from young adulthood to early middle age. But there remain differences among abilities with respect to the attainment of peak age as well as the degree to which age changes accelerate with advancing age. There are, moreover, important Ability × Gender, Ability × Cohort, and Ability × Age interactions that complicate matters. We have noted systematic gender differences that favor women with respect to verbal meaning and inductive reasoning and favor men with respect to spatial orientation and number. In the more recent cross-sectional sequences, gender difference trends have emerged that suggest that women may decline earlier on fluid abilities, whereas men do so on the crystallized abilities. Although fluid abilities begin to decline earlier, crystallized abilities show steeper decrement once the late 70s are reached (cf. Schaie, 1983, 1990a; Schaie & Hertzog, 1983, 1986).

Cohort-related differences in the rate and magnitude of age changes in intelligence remained fairly linear for

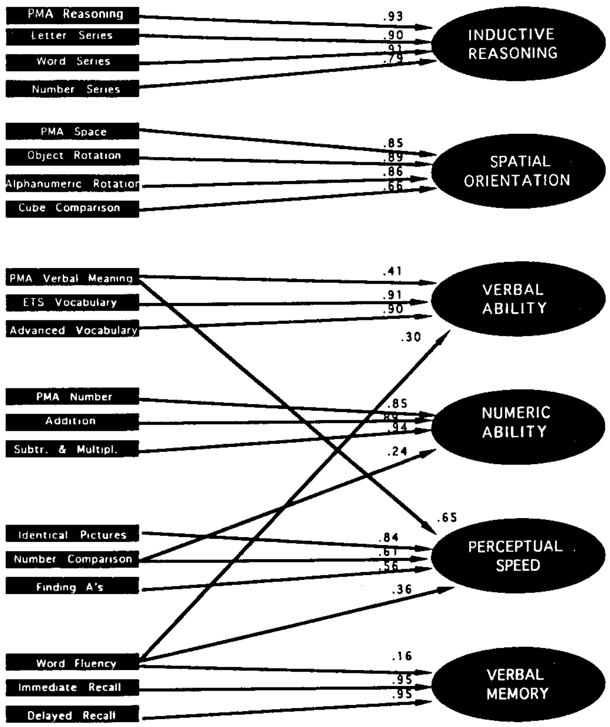
Figure 3
Longitudinal Estimates of Mean T Scores for Single Markers of the Primary Mental Abilities



Note. From 7-year within-subject data.

Figure 4

Measurement Model Linking the Observed Variables and Latent Ability Constructs



Note. Data from Schaie, Dutta, & Willis, 1991.

cohorts entering old age during the first three cycles in our study (until 1970); they have since shown substantial shifts. For example, rates of decremental age change have abated, while the earlier positive cohort trends have flattened as we begin to study members of the baby-boom generation. Patterns of socialization unique to a given sex role within a specific historical period may also be major determinants for the pattern of change in abilities. More fine-grained analyses, for example, suggest substantial gender differences when age changes are broken down into that proportions of change associated with either accuracy or speed (cf. Willis & Schaie, 1988).

Findings for measures of latent ability constructs. Realizing that single markers of an ability construct may limit the generalizability of developmental findings, we have added additional markers for each of six ability dimensions (inductive reasoning, spatial orientation, perceptual speed, numeric ability, verbal ability, and verbal memory), so that we can also report age difference and age change data at the latent construct level. For this purpose, the markers for a particular factor were weighted proportionally to their regression on the latest construct for the entire 1984 sample (cf. Schaie et al., 1991; see Figure 4 for a list of the individual marker variables and the measurement model linking the observed variables to the latent constructs). Factor scores were then computed for the six ability dimensions for the data collected in 1984 and 1991.

The cross-sectional patterns for the latent ability factor scores for our last test occasion (1991) have been plotted in Figure 5. This figure shows that there are virtually linear negative age differences from young adulthood to old age for four latent abilities: inductive reasoning, spatial orientation, perceptual speed, and verbal memory. However, numeric and verbal abilities show a far more concave pattern. Numeric ability does not reach an asymptote until the mid-40s, significantly lower performance is reached by age 60, but then another, lower plateau is attained. Verbal ability reaches an asymptotic plateau from middle adulthood (39 years) to early old age (67 years), with only modest age differences thereafter.

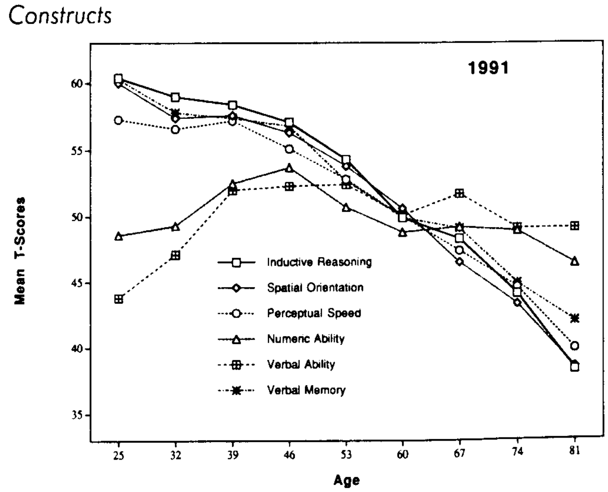
Next, I present longitudinal data at the construct level. These data (graphed in Figure 6) again represent the within-cohort estimates of seven-year changes, centered at the observed mean value for age 53, to be compared with the cross-sectional data. For the longitudinal data, a pattern of linear age-related decline for young adulthood appears plausible only for perceptual speed (also see Schaie, 1989b). Numeric ability shows an early plateau with linear decline, beginning in the 60s. The other four abilities, however, reach an asymptote by age 53 and show only modest decline thereafter.

Age at Which Decrements Can Be Detected and Magnitudes of Age Decrement

The SLS findings provide a normative base that can serve as guidelines for the determination of the ages at which declines attain practically significant levels that may be relevant for public policy issues such as mandatory retirement, age discrimination in employment, or in determining what proportion of the population can likely

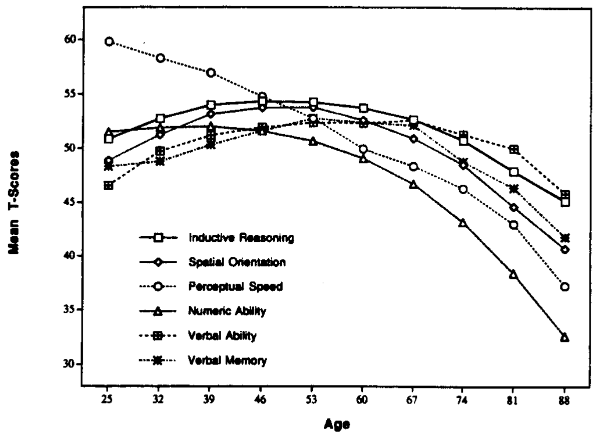
Figure 5

Cross-Sectional Mean Factor Scores for the Latent Ability Constructs



Note. 1991 data.

Figure 6
Longitudinal Estimates of Mean Factor Scores for the Latent Ability Constructs



Note. From 7-year within-subject data.

be expected to live independently in the community. I have had ample opportunity to present my findings for such purposes in legislative hearings, in rule-making processes, and as an expert in age-discrimination litigation. Furthermore, although our primary variables may be conceived as being primarily laboratory tasks, the relevance of these findings to everyday behavior has been established by demonstrating substantial relationships between the psychometric abilities and real-life tasks (Willis & Schaie, 1986a).

The longitudinal data for the single markers collected over the past 35 years indicate that average age decrements in psychometric abilities cannot be reliably confirmed prior to age 60, except for word fluency, which shows significant decline by age 53. However, reliable average decrement is indeed found for all abilities by age 67 (Schaie, 1990b; Schaie & Hertzog, 1983). This decrement is modest until the 80s are reached, and for most individuals, it is not a linear phenomenon but occurs in a stair-step fashion (Schaie 1989b). Even at age 81, fewer than one half of all observed individuals showed reliable decrements over the preceding seven years (Schaie, 1984). Average decrement before age 60 amounts to less than 0.2 *SD*, but by age 81, average decrement increases to approximately one standard deviation for most abilities (Schaie, 1983, 1984). At the latent construct level, there are modestly positive age changes from young adulthood to age 60 for inductive reasoning, spatial orientation, verbal ability, and verbal memory, but numeric skill declines by about 0.25 *SD* and perceptual speed slows by a full standard deviation. As compared with age 25, at age 88, there is virtually no decline in verbal ability; however, inductive reasoning and verbal memory have declined by better than 0.5 *SD*, spatial orientation by almost 1 *SD*, and numeric ability and perceptual speed have declined by more than 1.5 *SD*. Much of the late life decline, however, must be attributed to slowing of processing and response speed. When age changes in perceptual speed are removed from the other abilities, their magnitude of age decrement is significantly reduced (e.g., Schaie, 1989c).

Patterns and Magnitude of Generational Differences

Results from the SLS have conclusively demonstrated the prevalence of substantial generational (cohort) differences in psychometric abilities (Schaie, 1983, 1990b; Schaie & Hertzog, 1986; Willis, 1989). The cohort trends differ in magnitude and direction by ability and cannot therefore be determined from composite IQ indices. Cohort gradients for our single ability markers are shown in Figure 7, and in Figure 8 for the latent constructs (factor scores). These cohort gradients are obtained by differencing successive cohorts observed at the same age. For the single markers, these estimates are based on cohort differences at up to five different age levels. For the latent constructs, only one common age level was available for each cohort pair.

With respect to the single markers, almost linear positive cohort shifts were observed for inductive reasoning and verbal meaning, with a more spasmodic positive shift for spatial orientation. These cohort differences are substantial and account for differences of more than 1 *SD* between the earliest and latest cohorts. On the other hand, response on our measure of number skill peaked with the 1924 birth cohort and declined progressively thereafter by about 0.5 *SD*. More recently born cohorts are also at a disadvantage when compared with prior cohorts on the variable of word fluency (Schaie, 1990b). From these findings, we concluded that cross-sectional studies used to model age change overestimate age-related decline prior to the 60s for those variables that show neg-

Figure 7
Cohort Gradients for the Single Markers of the Primary Mental Abilities

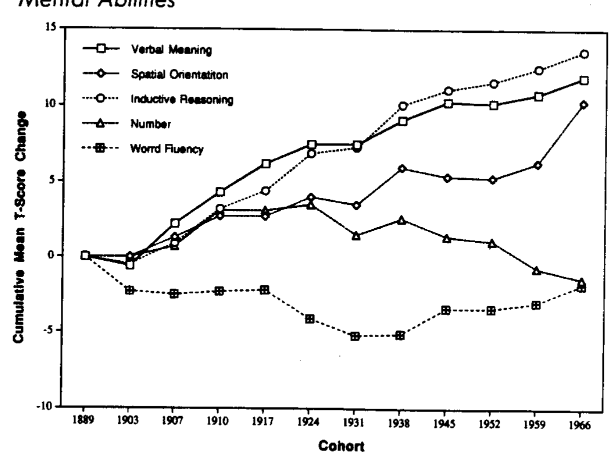
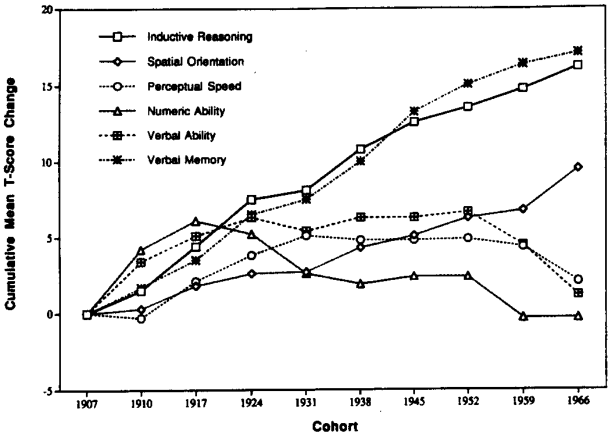


Figure 8
Cohort Gradients for the Latent Ability Constructs



ative cohort gradients and underestimate such declines for the variables with positive cohort gradients. These conclusions are supported further by an examination of the cohort gradients for the factor scores. Virtually linear positive gradients across birth cohorts from 1907 to 1966 were found for inductive reasoning and verbal memory, amounting to a cohort difference of about 1.5 *SD* from the earliest to the latest cohort. Spatial orientation also showed a positive cohort gradient, but of a somewhat smaller magnitude. By contrast, we find concave cohort gradients for perceptual speed, numeric ability, and verbal ability. For these latter abilities, there seems to be a positive gradient for cohorts born in the first quarter of the century, a plateau for the depression cohort.

A number of factors have been implicated for these dramatic cohort differences. Increased level of formal education appears to be the most explanatory factor for those abilities showing increments for successive cohorts. For those abilities showing a curvilinear pattern, shifts in educational strategies and intensity of exposure to relevant materials may be most the most important antecedents of cohort differences.

To supplement the work on generational differences in abilities among unrelated individuals, we have recently studied family members of our longitudinal study participants (Schaie et al., 1992, 1993). Most work in developmental behavior genetics has been conducted by means of twin studies. It has only recently been recognized that because of the unique characteristics of twins, broad generalizations from such studies will be limited and corroborative data are needed from family studies of parent–offspring and nontwin siblings. In the past, such studies used parents and their young offspring and young sibs; our study is the first effort to explore systematic family similarity through adulthood as well as to test for stability of such similarity over time.

An average family similarity of about .25 was observed for virtually all mental abilities and our measures of flexibility. Similarities were found for both parents and their offspring (adult children) and for siblings (brothers and sisters). The two exceptions to this finding were for the attitudinal measure of social responsibility (Schaie & Parham, 1974) and for a measure of perceptual speed, neither of which seem to display heritable characteristics. The magnitude of parent–offspring and sibling similarity differed for specific abilities, and the overall similarity was somewhat greater for parent–offspring pairs. The size of the correlations were also comparable with those found between young adults and their children in other studies (e.g., Defries et al., 1976). Because of changes in our society, it has been argued that there ought to be a reduction in family similarity for younger as compared with older parent–offspring pairs. The possible reduction in shared environmental influence is thought to be due to increased outside influences in the more recent generation. However, this proposition could be supported only for inductive reasoning, wherein the old and middle generations showed somewhat greater similarity than the younger generation. For other abilities, we found stability, and for some abilities (verbal meaning and spatial orientation), even an increase in family similarity for more recent generations. Correlating relative performance with the longitudinal target subjects over 7, 14, and 21 years of age, moreover, provided strong evidence for stability of family similarity over time and age.

Stability of Psychometric Ability Structure

Ever since the early factorial studies of age differences in the factor structure of the Wechsler Adult Intelligence Scale (WAIS; Cohen, 1957), we have been aware of the fact that there is a distinct possibility that a particular observed marker variable may not retain the same relationship to the underlying latent construct that is presumed to measure. Such shifts in the regression of observed variables on the latent construct, if found, would impose significant restrictions on the interpretability of age changes and age differences measured with single markers. As soon as we had collected multiple marker data, we proceeded with cross-sectional factor analyses of the invariance of ability structure over the entire age range included in our study. Most recently, we have also conducted longitudinal factor analysis over the seven-year interval for which multiple marker data are available.

The most stringent definition of factorial invariance would require that the factor loadings, factor variances, and factor covariances can be constrained equally across all comparison groups (complete metric invariance). A somewhat less stringent criterion that is more reasonable when applied to developmental studies is to allow differences in the factor variances and covariances but retain the requirement for equality of the factor loadings across comparison groups (semimetric invariance). In the recent literature on factorial invariance, an even less stringent criterion is suggested to demonstrate factorial invariance. This latter criterion requires only that the same number of factors and the same factor patterns prevail, so that across comparison groups the same tests load significantly on their hypothesized factor and can be set to zero for all other factors (configural invariance; also see Horn, 1991; Horn, McArdle, & Mason, 1983).

In the cross-sectional comparisons, we were able to demonstrate configural invariance (maintenance of factor pattern) but not metric factor invariance (invariance of the pattern coefficients) across a wide age–cohort range (ages 29 to 81). Differences in the regression weights assigned to the individual marker variables, however, were minor for the age range from 39 to 77 years. They were not inconsequential, however, for both the youngest and oldest groups studied (Schaie et al., 1989).

In the longitudinal factor analyses, we first tested the fit of the entire sample of subjects tested in both 1984 and 1991. In this analysis, we were able to demonstrate semimetric invariance of factor structure over seven years. That is, allowing the factor variances and covariances to vary over time, we obtained significant improvement of model fit. However, no such improvement was obtained when we freed the constraints across time on the factor loadings, indicating that there was no significant change over time in the regression of the observables upon the latent factors. We then tested the fit to the common model (see Figure 4) for six subsamples that were observed from mean ages 32 to 39, 46 to 53, 53 to 60, 60 to 67, 67 to 74, and 76 to 83, respectively. As we expected from the earlier cross-sectional analyses, we can accept invariance of factor patterns but not of the regression coefficients across groups. Within groups, once again, we obtain improvement in model fit if we allow the factor variances and covariances to vary over time, but we can accept the stability of the regression weights across time in the individual groups as well (semimetric invariance). These findings strongly suggest greater stability of individual differences within cohorts than across cohorts, and provide another argument for the superiority of longitudinal data.

Antecedents of Individual Differences in Age-Related Change

The unique contribution of a longitudinal study such as the one described here is the investigation of individual differences in antecedent variables that lead to early decrement for some persons and maintenance of high levels of functioning for others, well into very advanced age. We have implicated a number of factors that account for these individual differences, some of which have been shown to be amenable to experimental intervention. In each case, we tested and rejected reciprocal causal models. The variables identified to reduce the risk of cognitive decline in old age include the following:

1. The absence of cardiovascular and other chronic diseases. We do not claim a direct causal linkage, rather we suspect that the same behaviors that lead to the early onset of chronic diseases also reflect lifestyles that are unfavorable for the maintenance of high levels of cognitive functioning (Gruber-Baldini, 1991; Hertzog et al., 1978).

2. Living in favorable environmental circumstances as would be the case for those persons characterized by high SES. These circumstances include above-average education, histories of occupational pursuits that involve high complexity and low routine, above-average income, and the maintenance of intact families (Gribbin et al., 1980; Schaie, 1984).

3. Substantial involvement in activities typically available in complex and intellectually stimulating environments. Such activities include extensive reading habits, travel, attendance at cultural events, pursuit of continuing education activities, and participation in clubs and professional associations (Gribbin et al., 1980; Schaie, 1984)).

4. Individual's self-report of a flexible personality style at midlife as well as flexible performance on objective measures of motor–cognitive perseveration tasks (Schaie, 1984).

5. Being married to a spouse with high cognitive status. Our studies of cognitive similarity in married couples suggest that the lower functioning spouse at the beginning of marriage tends to maintain or increase his or her level vis à vis the higher functioning spouse (Gruber & Schaie, 1986).

6. The maintenance of high levels of perceptual processing speed into old age (Schaie, 1989c). As indicated earlier, aging effects on other cognitive abilities tend to be confounded with the perceptual and response speed required to process the tasks used to measure these abilities. Thus, individuals who remain at high levels of perceptual speed are also at advantage with respect to the maintenance of other abilities.

7. Rating one's self as being satisfied with one's life's accomplishment in midlife or early old age. Such individuals seem to be at advantage when assessed at a later age.

An attempt has also been made to apply event history methods to develop life tables for the occurrence of decline events on the five single-ability markers and to develop a calculus that allows estimation of the most probable age at which an individual can expect to experience decline on each of these abilities (Schaie, 1989a). The most highly weighted variables in this calculus that predict earlier-than-average decline are significant decrease in flexibility during the past seven-year period, low educational level, male gender membership, and low satisfaction with life success.

Reversing Intellectual Decline by Educational Interventions

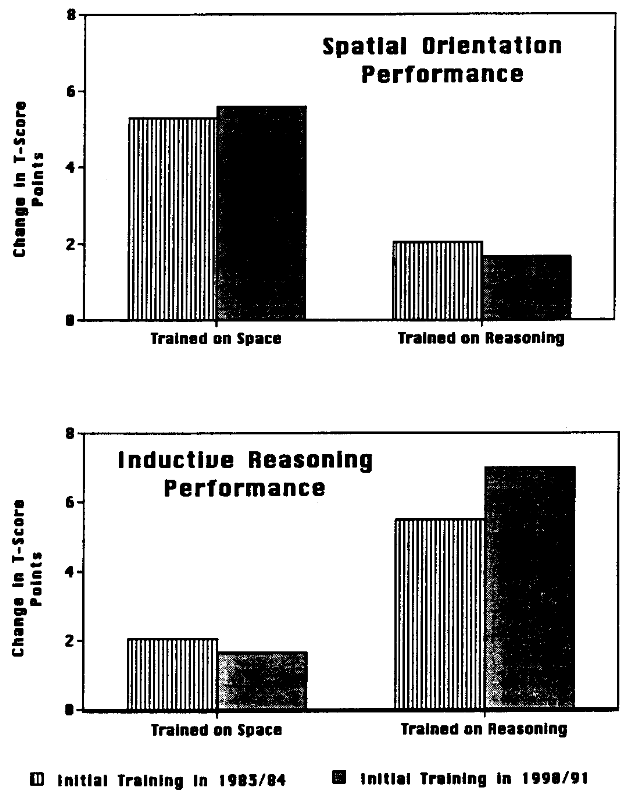
Because longitudinal studies permit tracking individual levels over time, Sherry Willis and I were able to design interventions that have remediated known intellectual decline and have also reduced cohort differences in those individuals who remained stable in their own performance over time but who became disadvantaged when compared with younger persons. Because fluid abilities tend to decline earlier and are thought to be more resistant to educational intervention, we proceeded to design interventions specific to the abilities of inductive reasoning and spatial orientation. Dr. Willis conducted task analyses of our assessment battery for these abilities and then developed training material sufficient to provide five one-hour sessions of individual strategy training. We selected subsamples of individuals who were 65 years of age or older in 1983 and did so again in 1991. Subjects were classified, using a 1 SEM confidence interval about base performance criterion, as to whether they had declined over the previous 14 years on one or both of the abilities of interest. If they had declined on only one ability, they were assigned for training with respect to that ability. If they had declined on both abilities or had remained stable on both abilities, they were assigned to the two training conditions at random. All of the participants of the training study received the full cognitive battery twice in a pretest–training–posttest design, with each training group serving as the control for the other training condition.

In the initial training study, conducted in 1983–1984, we trained 228 subjects. Approximately two thirds of our experimental subjects showed significant improvement, and about 40% of those who had declined significantly over the prior 14 years were returned to their predecline level (Schaie & Willis, 1986). An additional 179 subjects (not previously trained and selected to match the sample in the first study) were initially trained in 1990–1991. As suggested earlier, those subjects who remain in the study for at least 14 years have somewhat more favorable demographic characteristics and base ability levels than those not available because of attrition (cf. Schaie, 1988). However, they are quite comparable at base levels across training groups, and cohort differences between the 1983 and 1990 samples are similar to those observed for the entire data set.

Figure 9 shows the magnitude of training gain from pre- to posttest for the original study and for the replication. Training effects amounted to approximately 0.5 *SD*. Training was somewhat more effective for inductive reasoning than for spatial orientation. There was also a trend for men to benefit more from inductive reasoning training, whereas women benefited more from spatial orientation training (to the extent of removing the reliably demonstrated gender difference for that ability subsequent to training). Training was also somewhat more effective for those individuals who declined prior to the intervention. We were also able to show that we did not simply train to the test, but rather trained at the ability (latent construct) level (Willis & Schaie, 1986b), and that the training did not disturb the ability structure described earlier (Schaie et al., 1987), thus providing evidence that training results in quantitative change on the targeted constructs without any accompanying qualitative shifts in the skills that were trained. Training gains seem to represent largely increased accuracy for men, but a mix of improvement in accuracy and speed for women (Willis & Schaie, 1988).

In our recent follow-up of the initial training, we were able to reassess 141 subjects after an average interval of seven years. These individuals were then given additional booster training for the same ability on which they had been trained initially. We were able to show that persons trained remain, on average, at a significant advantage over their controls even after seven years. The advantage resulting from the initial training, furthermore, could be substantially increased by a five-hour course of booster training.

Figure 9
Magnitude of Training Effects From Pre- to Posttest



Although these interventions were conducted with specific laboratory tasks, their relevance to the subjects ability to cope with the demands of daily living has been supported by showing substantial correlations between the psychometric abilities that we trained with measures of practical intelligence (Willis & Schaie, 1986a) and with objective measures of performance on instrumental tasks of daily living (Willis, Jay, Diehl, & Marsiske, 1992). The results of the cognitive training studies conducted with our longitudinal subjects suggest that observed ability declines in many community-dwelling older people are probably due to disuse and are consequently reversible, at least in part, for many persons.

Summary

The Seattle Longitudinal Study has charted the course of selected psychometric abilities from young adulthood through old age and has investigated individual differences and differential patterns of change. Our concern has not been limited to demonstrating the presence or absence of age-related changes and differences; we have also provided data on the magnitude and relative importance of the life-course changes that we have studied over the past 35 years. In addition, we were able to identify some of the contextual, health, and personality variables that offer explanations for differential change over time, knowledge of which provide a conceptual basis for possible interventions. We have also demonstrated the invariance of psychometric ability structures within groups over time and, at a less rigorous level, across groups. Within the context of the SLS, we have studied cognitive similarity within parent–offspring and sibling pairs. Finally, we have designed cognitive interventions that have been successful in remediating carefully determined declines and in improving the cognitive functions of older persons who have remained stable.

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