Longitudinal Studies in Cognitive Aging: An Overview

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Paper presented at the
1994 Cognitive Aging Conference
Atlanta, Georgia
April 7, 1994

Preparation of this paper was supported in part by a research grant, R37 AG08055-06, from the National Institute on Aging

LONGITUDINAL STUDIES IN COGNITIVE AGING: AN OVERVIEW

I will begin this overview lecture by briefly reminding listeners of the essential differences in the conclusions that can be drawn from cross-sectional and longitudinal studies, emphasizing the particular advantages as well as the liabilities of longitudinal data sets. I will then try to summarize some conclusions that can presently be reached from the longitudinal literature on cognitive aging. I will also have some comments on the shape of longitudinal age gradients and how these shapes may be changing as successive cohorts enter old age. I will then briefly summarize what I think are the main contextual factors that seem to me to be important corollaries of cognitive aging that need to be monitored in longitudinal studies, and that may be instrumental in explaining shifts in level and rate of cognitive performance in advanced age. And finally, I will have some comments on certain issues in terminal drop research. Although my examples will primarily drawn from my own work in the context of the Seattle Longitudinal Study (Schaie, 1993, 1994b) concerned with age changes in psychometric abilities, the issues discussed generalize to the entire domain of cognitive aging.

What are the Advantages and Disadvantages of Longitudinal Studies in Cognitive Aging

I begin by reminding my listeners that the study of all developmental processes is bounded by the constructs of age, cohort (or time of birth) and period (or time of measurement). I will not review here the tortuous debate over how or whether these constructs can ever be unambiguously unconfounded, or whether there are any statistical procedures that can provide us with clearly differentiated estimates for these three components of development. In this context I refer the audience to my own earlier writing on this topic and to that of other contributors to that literature (see Table 1, from Schaie, 1983). However, I do need to provide some definitions, that will allow us better to distinguish between what unique contributions we can expect from longitudinal studies, that would go beyond the inferences that simple cross-sectional age-comparative research would provide.

Table 1 and Figure 1

If you will examine Figure 1, you will note that I am showing you a cohort by age matrix with time-of-measurement (period) entered in the cells of that matrix. Note that each column represents an age-comparative cross-sectional data set, while each row represents a single-cohort longitudinal data set. As an aside, the latter could represent repeated measurements or it could represent a series of random samples drawn at successive measurement occasions from the same population frame. Each diagonal represents a time-lagged data set; that is, different samples of the same age measured at successive measurement times. In Baltes' (1968)

terminology, two or more rows represent a longitudinal sequence, while two or more diagonals represent a cross-sectional sequence.

Advantages of Longitudinal Studies

The principal advantage of the longitudinal approach to the study of cognitive aging is, of course, that only longitudinal data permit gathering of information on intra-individual change. By contrast, longitudinal data allow inferences only about population parameters and about inter-individual differences. Unless one assumes that the subjects to be studied live in a constant environment, and that each cross-sectional comparison group is an equivalent random sample from the general population, it is not possible to infer age changes from age differences. Five distinct rationales can be listed that argue for the desirability of longitudinal studies (cf. Baltes & Nesselroade, 1979; Schaie, 1983).

1. *Direct Identification of Intraindividual Change.* Individual change can be quantitative or qualitative, such as the transformation of one behavior into another. Alternatively, changes can occur in the regression of latent constructs upon their observed markers, over the course of development. All such transformations require the lapse of time, and can not be inferred from single occasion observations.

2. *Identification of Interindividual Variability in Intraindividual Change.* Longitudinal studies allow assessment of variability among different individuals in their behavioral course over time. The identification of growth

curve typologies depends upon an examination of similarities and differences in developmental patterns. That is, we need longitudinal measures of change within individuals. Without longitudinal data it would not be possible to answer the question whether or not parameter estimates are descriptive of the development of and *particular* individual. Of course, longitudinal data area also required for the useful hypothesis-gathering source of single subject research.

3. *Interrelationships Among Intraindividual Changes.* Modern aging research is cognizant of the sterility of single variable experiments; hence, most contemporary research is concerned with multivariate variable sets. Longitudinal studies alone, by virtue of multiple observations over time, allow us to discover structural relationships among behavior changes within a multivariate framework. This important feature of longitudinal data sets is particularly important for the identification of progressive differentiation processes as well as for any kind of systems research.

4. *Analysis of the Determinants of Intraindividual Change.* If we wish to draw causal inferences from data, the longitudinal studies are the appropriate base for the identification of time-ordered antecedents and consequents. Longitudinal data alone can serve to identify causal processes that involve discontinuities, such as the so-called sleeper effects, or in the case where causal process may be multidirectional.

5. *Analysis of Interindividual Variability in the Determinants of Intraindividual Change.* Longitudinal studies are required also to permit the

identification of time-ordered antecedents to provide the necessary, albeit not sufficient, conditions for causal interpretation of changes that may occur. Only longitudinal data can reveal discontinuities associated with so-called "sleeper effects," and allow the examination of causal chains which are multidirectional or involve multivariate patterns of influence.

Disadvantages of Longitudinal Studies

I now must caution, however, that those embarking on longitudinal studies pay a heavy price, not only in the time and effort required. The reason for this is that longitudinal studies have the typical internal and external validity problems common to all quasi-experimental research designs. In a cross-sectional study, the major internal validity threat is that of selectivity; that is, the non-equivalent nature of the groups to be compared. But cross-sectional studies control for experimental mortality (attrition), history, reactivity, statistical regression, and instrumentation effects by assessing each subject only once. In longitudinal studies, by contrast, all these validity threats must be dealt with, often with suitable control groups, or collateral data collections. These internal validity threats are of particular concern in single-cohort longitudinal designs. In such studies, for example, the age effect will be confounded with time-of-measurement (period) effects. In other words period-specific influences may either suppress or exaggerate true age-related change. To detect the likely presence of such effects, it is always preferable to follow multiple cohorts, and in order to permit estimation of other than linear growth curves and to control for regression effects to include at least three data points in a study. In addition, as we shall see, multiple-cohort studies permit the modeling of changes in rate of aging across cohorts.

One way in which longitudinal studies can control for these validity threats would be by choosing the approach of comparing repeated random samples from the same cohort. Note, however that this is not a complete fix, because such data do not allow the modeling of individual growth curves.

It is rarely possible for any single investigator to follow the same subjects over the entire adult age range. As a consequence, short-term longitudinal studies have become justifiably popular. Such studies follow a cross-sectional sample over a relatively brief time interval, with sufficiently large sub-sets to cover the entire age range of interest. If the longitudinal follow-up period is equal in length to the boundaries of the cross-sectional subsets, it is then possible to model longitudinal growth curves, by estimating cumulative within subject change over the time interval studies. The limitation of this approach is that we must assume that rate of change will be constant across cohorts; and assumption that thus far has received only limited testing. However, as multiple follow-ups occur, the composite longitudinal estimates can then be validated, albeit by means of ever more select samples as time passes (cf. also Schaie, 1994a).

What is the Nature of Findings From Longitudinal Studies of Cognitive Aging?

One of the major reasons why cross-sectional data can not be used to model age changes is, of course, the fact that it is quite difficult to match age-comparative samples in all characteristics other than the variable to be studied or manipulated. Hence, the nature of cohort differences becomes of interest in understanding the discrepancies between cross-sectional and longitudinal studies.

Virtually all of the literature that compares cross-sectional and longitudinal studies of cognitive aging reports findings that for comparable age ranges longitudinal data show less decremental change in those instances where there have been positive cohort differences over the age/cohort range investigated. This seems to be the case particularly for measures of fluid abilities as well as for recognition measures of verbal abilities and associative memory. On the other hand longitudinal studies show greater decremental change for abilities where there seem to have been negative cohort trends, such as numeric ability, perceptual speed, and word recall. I will illustrate this point, first of all by showing the cohort gradients for six latent abilities (i.e., multiply marked factor scores) obtained in the Seattle Longitudinal Study by comparing birth cohorts in seven-year intervals from a base cohort born in 1889 to the youngest adult cohort in our latest study cycle born in 1966 (see Figure 2).

Figure 2

Next, I will show cross-sectional data for the same latent ability scores for our most recent cross-sectional sample, tested in 1991, and longitudinal estimates obtained from aggregating seven-year changes across all our data collections, over a similar age range. I hope you will agree that the differences between the cross-sectional and longitudinal data are quite substantial. But note, that these data must be used to address different questions. The cross-sectional data are clearly relevant if we wish to ask the question as to what differences between groups at different life stages are at a particular point in time. These data suggest that for four of the six latent abilities there is an increasing disadvantage at each successive age as compared to the preceding younger age. On Verbal and Numeric Ability, there is increasing advantage until the mid-forties and then relative stability until old age. Because of the substantial cohort differences shown earlier, these data, however, do not represent well changes within individuals over their life course.

Figure 3

To understand intra-individual development, it is the longitudinal data, that provide our best estimates as to what the average "maturational"

pattern within individuals is likely to be. In our example, it is only Perceptual Speed that follows the virtually linear decline model suggested by the cross-sectional data. In contrast, to the cross-sectional data, Numeric Ability shows a young adult plateau, with relatively early decline. All other abilities peak in late midlife, and show only relatively modest decline until the eighties are reached.

Relative Invariance of Latent Constructs in Cross-Sectional and Longitudinal Studies of Cognitive Aging

A major concern in any studies involving the age variable is the question whether the relationship between observed variables and the latent constructs they are thought to represent remains invariant over time. Such invariance is a necessary assumption to make comparison of level scores across age whether at the observed or latent construct level.

The most stringent definition of factorial invariance requires that the factor loadings, factor variances and factor covariances can be constrained equal 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 (semi-metric invariance). An even less stringent criterion suggested by Horn requires only that the same number of factors and the same factor patterns prevail, such 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 cf. Horn, 1991; Horn, McArdle, & Mason, 1983).

In my own work it has been possible to demonstrate configural invariance (maintenance of factor pattern) but not metric factor 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 were minor for the age range from 39 to 77 years; but they were not inconsequential for either the youngest and oldest groups studied (Schaie, Willis, Jay, & Chipuer, 1989).

By contrast, in longitudinal factor analyses we were able to demonstrate semi-metric invariance of factor structure over seven years. Allowing the factor variances and covariances to vary over time, a significant improvement of model fit could be obtained. However, no such improvement occurred when e constraints across time upon the factor loadings were relaxed, 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 a common model (see Figure 4) for six sub-samples 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

except for the oldest group, we can accept the stability of the regression weights across time in the individual groups as well (semi-metric invariance). These findings strongly suggests greater stability of individual differences within cohorts than across cohorts, and provides another argument for the superiority of longitudinal data.

Figure 4

Are there Changes in Rate of Cognitive Aging: The Role of Longitudinal Data

Even different data, based on multi-cohort comparisons of slopes, however, are needed to address the question as whether there are changes in the rate of age changes across successive generations. I will next show some data obtained from three groups of individuals all of whom were followed longitudinally over the age range from 60 to 81 years, but who represent cohorts differing by seven years of age in birth cohort (which means, of course, that the same age ranges are also observed staggered by seven years.

In the next figure data are charted for the directly observed variables of Space and Reasoning from the Thurstone PMA test (see Figure 5). Two different patterns emerge: The top graph for Reasoning shows not only an increase in level for the most recently born cohort, but also shows a flattening of the decrement (a slowing in the rate of decremental age changes). By contrast, for the Space test, there is a level increment for the most recent cohort only at age 60; and consequently the rate of aging on this variable appears to have increased. These data could also obviously be used to model individual growth curves that could then be examined for inter-individual differences in growth patterns via the increasingly popular methods of hierarchical analyses a la Bryck and Raudenbush.

Figure 5

It should be noted, though, that these data differ from the kind of cross-sequential comparisons of cohorts differing in age possible from two point short-term longitudinal studies such as that by Small, McDonald-Miszczak, and Dixon (1992). However, as soon as three assessment points are available, than cohort-sequential comparisons are possible and I hope we will see them in Dave Hultsch's presentation, or at least they are certainly possible with his data set. I believe, Lars Nilsson will also present us with a data collection design that eventually will make possible such cohort comparisons.

Contextual Factors that Effect Differences in Level and Rate of Cognitive Aging

Perhaps the most unique contribution of longitudinal studies of cognitive aging 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. Scrutiny of the relevant literature would seem to implicate a number of factors that account for at least some of these individual differences. Some of these factors may be amenable to experimental intervention, and thus provide the basis for the development of cognitive and other behavioral intervention paradigms.

Variables that have been identified to reduce the risk of cognitive decline in old age include:

(1) *The absence of cardiovascular and other chronic diseases*. Although there may not be a direct causal linkage, it may be suspected that those behaviors that lead to the early onset of chronic diseases will also reflect life styles that are unfavorable for the maintenance of high levels of cognitive functioning (Gruber-Baldini, 1991; Hertzog, Schaie, & Gribbin, 1978).

(2) *Maintenance of high levels of perceptual processing speed into old age* . 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 (Schaie, 1989b). Hence, individuals who remain at high levels of perceptual speed are also at advantage with respect to the maintenance of other abilities.

(3) *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, Schaie, & Parham, 1980; Schaie, 1984).

(4) *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, Schaie, & Parham, 1980; Schaie, 1984).

(5) *Individual's self-report of a flexible personality style at midlife as well as flexible performance on objective measures of motor-cognitive perseveration tasks.* Reliably determined drops on these characteristics have bee identified as precursors of significant cognitive decline (Schaie, 1989a).

(6) *Being married to a spouse with high cognitive status.*. 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 a vis* to the higher functioning spouse (Gruber & Schaie, 1986).

(7) Finally, *individuals who rate themselves as being satisfied with their life's accomplishment seem to be at advantage* (Schaie, 1989a).

Event history methods can be used to develop life tables for the occurrence of cognitive decline events on the cognitive variables of interest and a calculus can then be developed that allows estimation of the most probable age by which an individual can expect to experience specific cognitive declines (Schaie, 1989a). In our work, we developed such a

calculus for the five Thurstone PMA abilities. The most highly weighted variables in this calculus that predict earlier than average decline were significant decrease in flexibility during the past seven-year period, low educational level, male gender membership, and low satisfaction with life success.

Some Comments on Terminal Decline

Studies of terminal drop also depend upon the availability of longitudinal data, since the phenomenon needs to be represented as a drop in performance during a period prior to death. The terminal decline literature seems to remain controversial with some investigators providing data supporting the presence of the phenomenon while other can not seem to find convincing evidence. It seems to me. that one of the major problems in this literature is the non-comparability of ages of subject populations as well as the distance from death when the predictor variables were measured. Most terminal drop studies are really based on analyses of experimental mortality. Unfortunately, it is often virtually impossible to obtain complete records that distinguish those who have died from those who have been lost to followup for other reasons.

Interestingly enough, when careful followup is possible, one can show that terminal drop phenomena are most likely to be demonstrable in the old-old and very old. Because of the increasing dedifferentiation (increase in covariance) of many cognitive functions with advanced age, it becomes increasingly likely that many behavioral indicators may become molar indicators of system failure occurring relatively close to death. Such a phenomena is less likely in the young old, where death is frequently not the result of increasingly severe chronic conditions, but rather as a consequence of an acute insult. Thus terminal drop studies with the young-old are less likely to yield positive results. In fact, among the young-old it is quite likely that individuals who are suffering from disability or chronic disease, but who are still alive, will tend to show lower cognitive performance at the last available measurement point than those who have actually died (cf. Cooney, Schaie, & Willis, 1988).

Summary

I have tried to summarize for you the reasons why I believe that longitudinal data must be considered essential for many problems of interest to cognitive aging researchers. I reminded you that while cross-sectional data are important in identifying concurrent age differences in performance such data does not suffice to model problems that involve tracking behavior over time. I also commented on some of the disadvantages of longitudinal data, with respect to internal validity. I then provided a number of illustrative examples with respect to these issues. In particular, I suggested the need of longitudinal data for the modeling of differential rates of change with aging, the fact of greater invariance with respect to age in longitudinal than in cross-sectional data, and I discussed some issues with respect to terminal drop.

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Table 1

The Age-Cohort-Period Problem

Baltes, P. B. (1968). Longitudinal and cross-sectional sequences in the study of age and generation effects. *Human Development, 11*, 145-171.

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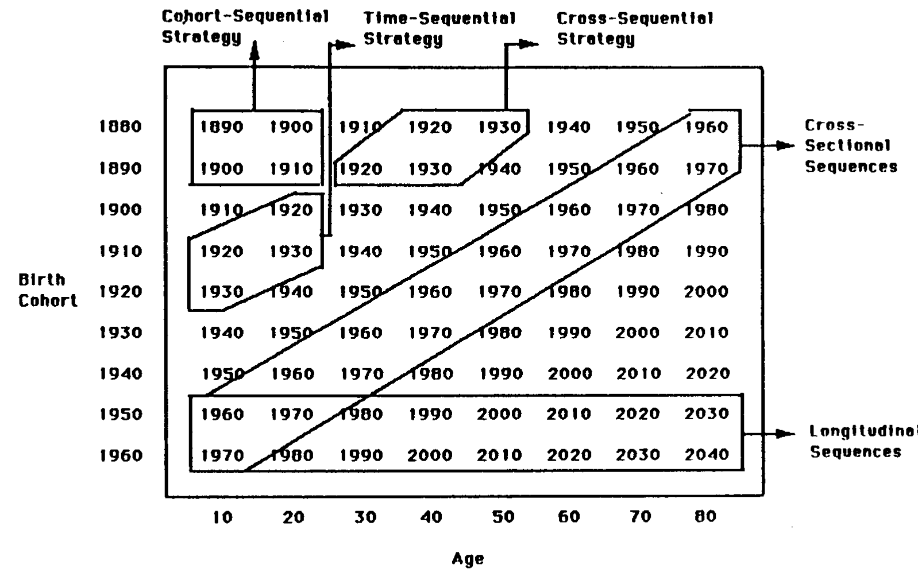
Figure 1



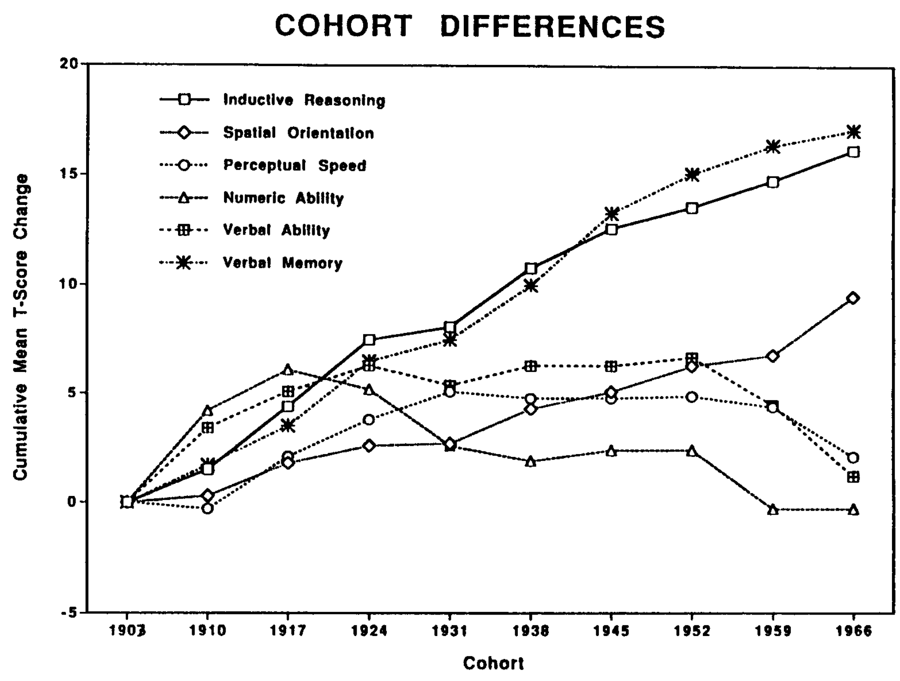


Figure 2

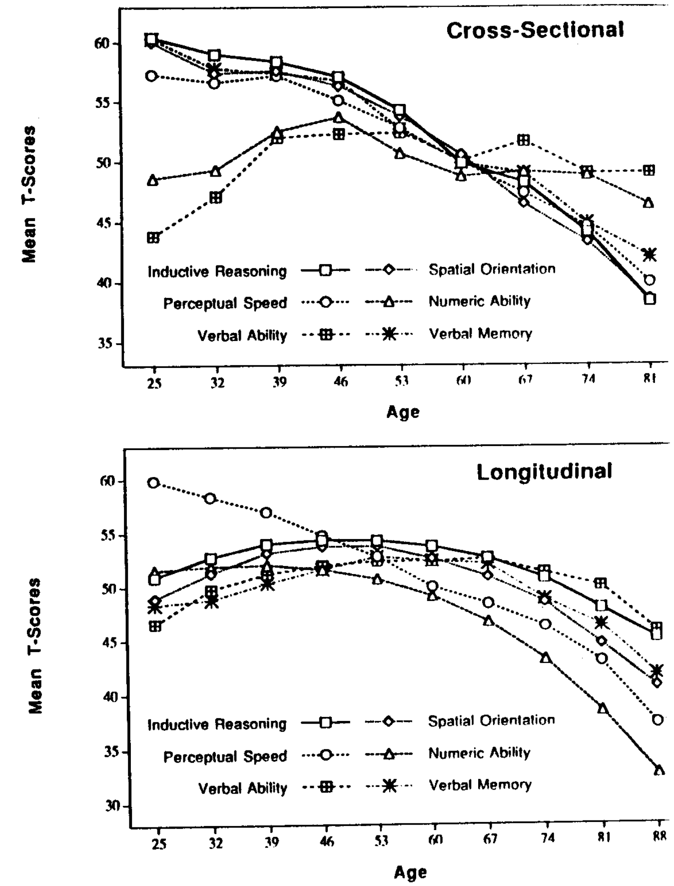


Figure 3

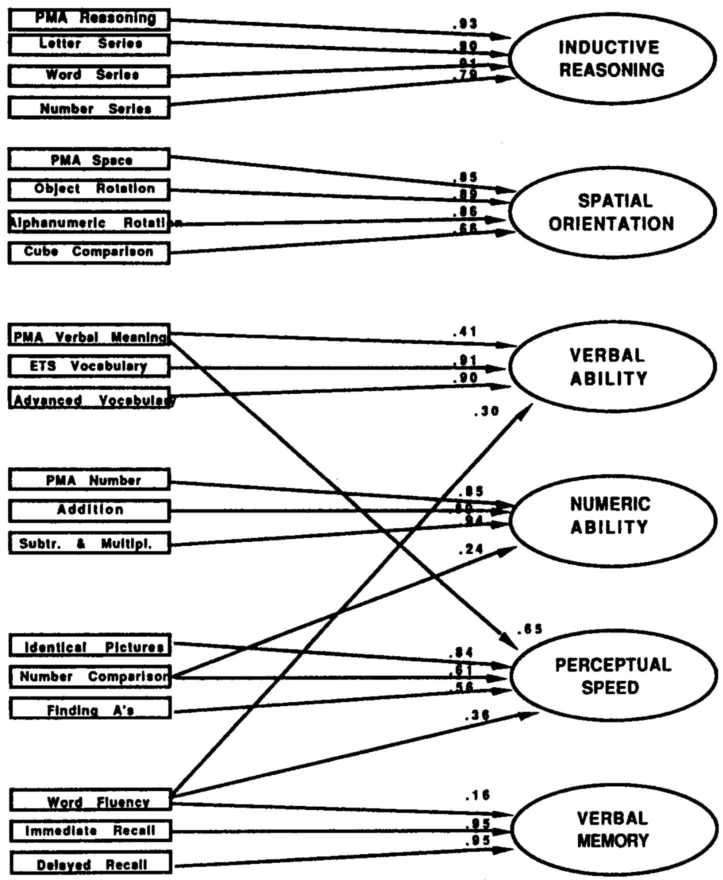


Figure 4. Measurement model linking the observed variables and latent ability constructs (after Schaie, Dutta, & Willis, 1991).

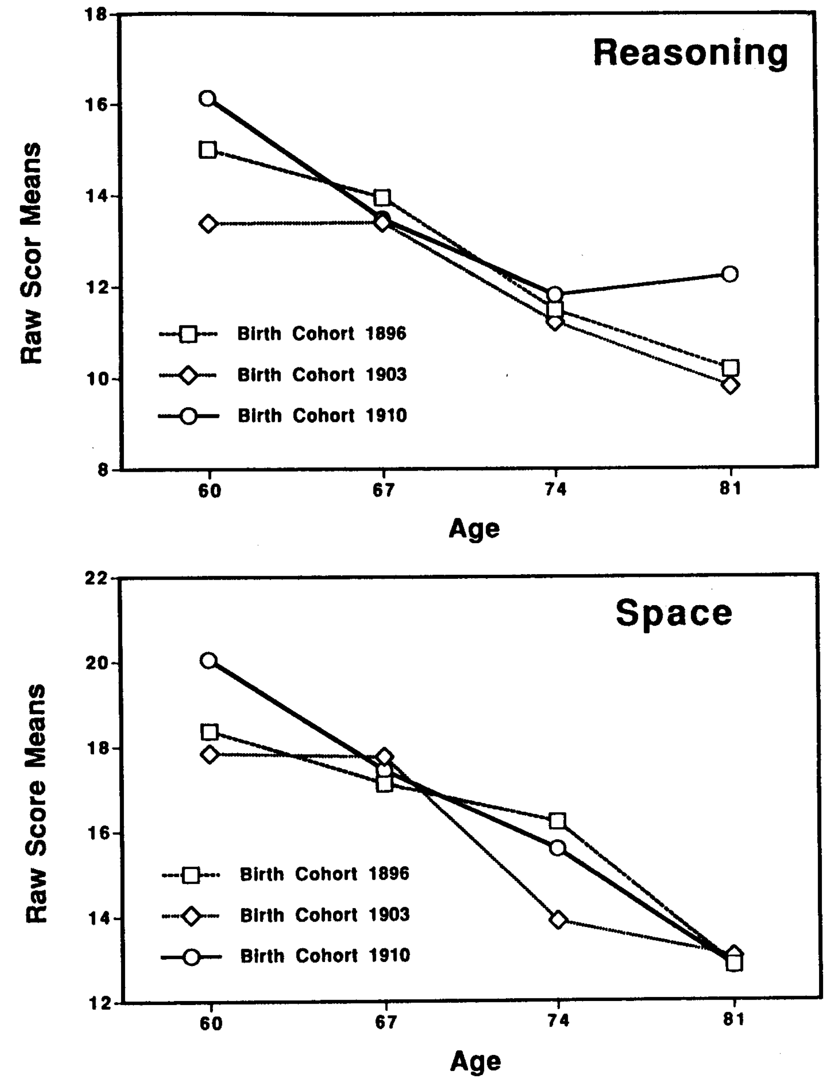


Figure 5