CHAPTER TWO

Methodological Issues in Aging Research

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Introduction

The purpose of this chapter is to examine some of the central issues in research on aging. Most of the content of the chapter, although oriented towards the special issues facing researchers interested in the life stages of adulthood and old age, is equally relevant to the study of earlier life stages. These earlier stages are characterized by the rapid growth and differentiation of behaviors. By contrast, growth slows in young adulthood, and middle adulthood is characterized by long-lasting stability, while early old age shows decline occurring in some but not all individuals. In advanced old age, rapidly declining performance is then the norm. A perhaps even more important distinction is provided by the fact that studies of early development are typically conducted over short temporal periods and limited age ranges while studies of adulthood cover large age ranges and may extend across different historical eras.

We begin this chapter by delineating the differences in conclusions that can be drawn from cross-sectional (or age-comparative designs) as contrasted to longitudinal (or within-group follow-up) research designs. Sequential research designs and related analytic strategies are then considered as possible ways to ameliorate the deficiencies of single time point cross-sectional and single-cohort longitudinal studies. Finally, we turn to an analysis of the threats to the internal validity of studies of adulthood and aging.

Cross-Sectional versus Longitudinal Designs

In developmental research, it is important to be clear about whether a study addresses age differences or age changes. Cross-sectional (or age-comparative) designs provide information about *age differences* by comparing groups of different people who vary in age but are assessed at the same point in time. In contrast, longitudinal (or within-group follow-up) designs involve the observation of the same individuals at two or more different times; thus, such data represent *age changes.*

Perhaps the best way to understand the differences between cross-sectional and longitudinal designs is to consider how the designs vary along the dimensions of age, cohort, and time (or period). Schaie (1965) presented a general developmental model that proposed that any developmental change could potentially be decomposed as being influenced by one or more of these three independent dimensions. These issues were also addressed in the sociological literature by Mason et al. (1973) and Ryder (1965). Schaie's general developmental model is reviewed below.

The general developmental model characterized the developmental status of a given behavior B to be the function of three components (i.e., age, cohort, and time), such that $B = f(A, C, T)$. In this context, age (A) refers to the number of years from birth to the chronological point at which the individual is observed or measured. Cohort (C) denotes a group of individuals who enter an environment at the same point in time (usually but not necessarily at birth), and time of measurement (T) indicates the temporal occasion on which a given individual or group of individuals is observed or measured. We note that the three components are confounded in the sense that once two are specified, then the third is known, similar to the confounding of temperature, pressure, and volume in the physical sciences. For example, if an individual from a cohort born in 1950 (C) is to be assessed in the year 2010 (T), then it is known that the age (A) of that individual will be 60 years at the assessment. Nevertheless, despite their confounded nature, each of the three components is of primary interest for some questions of interest in the developmental sciences, and it would be useful to estimate the specific contribution attributable to each component.

Both the traditional longitudinal design, following one group of individuals over several occasions, and the traditional cross-sectional design, measuring several age groups at one time point, are simply special cases of Schaie's general developmental model, in which one of the three dimensions does not vary, while the other two are confounded. Specifically, in cross-sectional studies, no differential time (i.e., period) effects can be observed because the data are all collected at one point in time. In addition, age and cohort are confounded in the cross-sectional design because the age groups being studied must, by definition, be drawn from different birth cohorts. Because age and cohort are confounded in a cross-sectional design, it cannot be known if any differences between age groups that may be found are actually due to age or whether such differences could be attributed to cohort differences.

In contrast, single-cohort longitudinal studies, by definition, cannot reflect any cohort differences, but confound the effects of age changes in the dependent variable with time (period) effects occurring over the calendar time during which change is assessed. Because the single-cohort longitudinal study confounds changes in age with changes due to the passage of time, we cannot be assured with this type of design that any observed behavioral change is due to a maturational change as opposed to an environmental change. For example, suppose that in 1997 we had asked a group of 20-year-olds their opinions about the level of security they would find acceptable for air travel. If we reassessed this group in 2002 (at age 25) and found that they would accept a greater amount of security measures for air travel, we could not be certain whether this increase was due to a change in age from 20 to 25 or to events that had occurred during the five years between assessments.

Investigators have sometimes compared samples of individuals at different ages (i.e., the cross-sectional method) and concluded that differences found on the dependent variable could be attributed to chronological age. However, research on the adult development of mental abilities has shown wide discrepancies between cross-sectional and longitudinal data collected on the same subject population over a wide age range. For some dependent variables, substantial age differences obtained in cross-sectional data were not replicated in longitudinal data, while for other dependent variables, longitudinal age changes reflected more profound decrement than was shown in the comparable cross-sectional age difference patterns (Schaie, 2004; Schaie & Strother, 1968).

Given the confounds involved in both the traditional cross-sectional and single-cohort longitudinal designs, it is unlikely that a single cross-sectional data set or even a single longitudinal data set would be able to answer many theory-based questions (Schaie, 1992, 2000; Schaie & Hofer, 2001). Further, although the necessity of longitudinal data for the study of age changes and intraindividual development is clear, such studies are plagued by their impracticable time line if one is interested in a large age range, such as the entire adult age span. However, data acquisitions that are structured as cross-sectional or longitudinal sequences (Schaie & Baltes, 1975; Baltes, 1968) can allow an initial data collection to be suitably extended so that theory-based questions about development can be answered (Schaie, 1992; Schaie & Willis, 2002). Sequential strategies, described in the next section, have been proposed to address these concerns.

Sequential Studies and Analysis Strategies

Sequential studies can be either cross-sectional or longitudinal. A *cross-sectional sequence* consists of two or more cross-sectional studies, covering the same age range, conducted at two or more times. For example, we might compare age groups ranging in age from 25 to 75 in 2005 and then repeat the study in 2015 by obtaining a new sample of individuals in each of the age groups, covering the same age range of 25 to 75 years. In contrast, a *longitudinal sequence* consists of two or more longitudinal studies, using two or more cohorts. For example, we might begin by studying a group of 25-year-olds in 2005, planning to assess these individuals every ten years until they reach age 75 in 2055. This is a simple, single-cohort longitudinal study. In 2015, if we also begin studying a new cohort of 25-year-olds, also planning to assess these individuals every ten years until they reach age 75, the data from these two single-cohort longitudinal studies comprise the simplest case of a longitudinal sequence.

To summarize, longitudinal sequences use the same sample of individuals from two (or more) cohorts repeatedly, while cross-sectional sequences use independent random samples of individuals (each observed only once) from cohorts covering the same age groups at two (or more) different points in time. The critical difference between the two approaches is that the longitudinal sequence permits the evaluation of intraindividual age change and interindividual differences in rate of change, about which information cannot be obtained from cross-sectional sequences.

Schaie's "most efficient design" (Schaie, 1965, 1977, 1994; Schaie & Willis, 2002) combines cross-sectional and longitudinal sequences in a systematic way. The "most efficient design" first requires the identification of a population frame that provides a reasonable representation of the full range of the dependent variables to be studied. Optimally, the population frame should be a natural one, such as a school system, health plan, broadly based membership organization, or the like. Also, the population should be fairly large, so that it is possible to assume that members leaving the population will on average be replaced by other members with similar characteristics, maintaining the consistency of the population (i.e., sampling with replacement). In the most efficient design, an age range of interest is defined at Time 1 and is sampled randomly at intervals that are optimally identical with the time chosen to pass between successive measurements. For example, if 10 years will elapse between the first and second measurements, then the samples should be drawn in 10-year age intervals. At Time 2, previous participants from the Time 1 data collection are retrieved and restudied, providing short-term longitudinal studies of as many cohorts as there were age intervals at Time 1. The whole process can be repeated multiple times with retesting of previous subjects (adding to the longitudinal data) and initial testing of new samples (adding to the cross-sectional data). A hypothetical data collection with three time points using Schaie's most efficient design is shown in Figure 2.1.

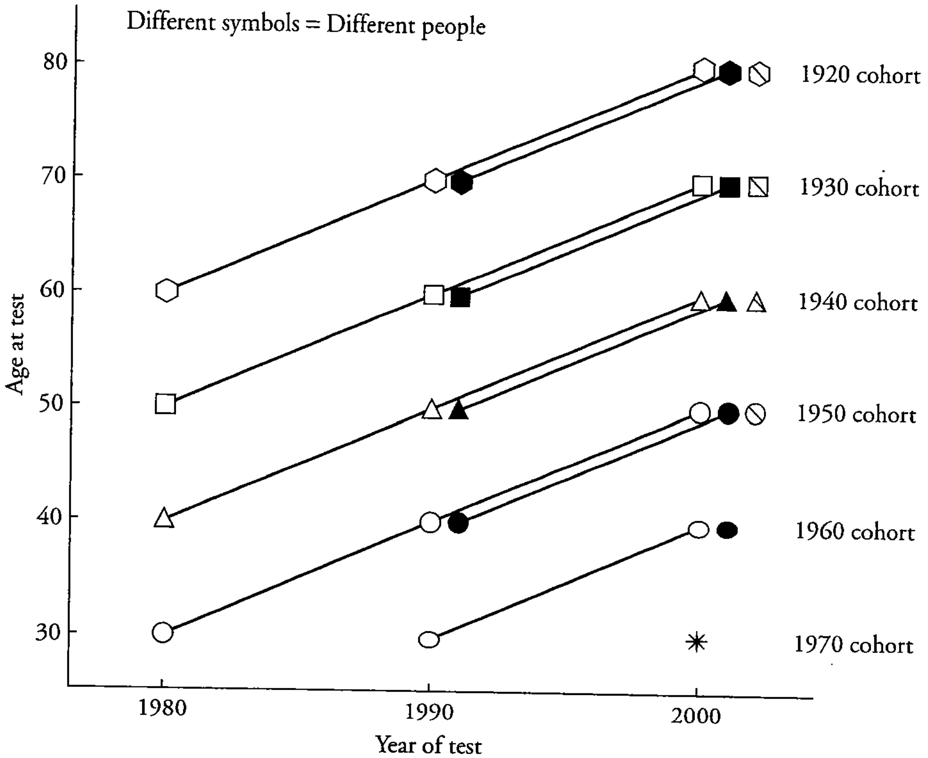

Figure 2.1 Schaie's most efficient design. (From Schaie & Willis (2002). Copyright 2002 by Prentice-Hall. Reprinted by permission.)

Table 2.1 Summary of the key features of the cohort-sequential, cross-sequential, and time-sequential analysis strategies

	Minimum requirements				
Strategy	*Ages*	*Cohorts/samples*	*Times*	*Contrasts*	*No effect*
Cohort-sequential	2	2	3	Age × Cohort	Time
Cross-sequential	3	2	2	Cohort × Time	Age
Time-sequential	2	4	2	Age × Time	Cohort

Data from the "most efficient design" or comparable designs can be analyzed in several ways to answer different research questions. Based on his 1965 general developmental model, Schaie described three sequential analysis strategies: the cohort-sequential strategy, the cross-sequential strategy, and the time-sequential strategy. It is important to note that the strategies proposed by Schaie should be viewed primarily as data analysis strategies rather than as data collection designs (Schaie & Baltes, 1975; Baltes, Cornelius, & Nesselroade, 1979; Schaie, 1994). Table 2.1 summarizes the key points of these three strategies and can be used as a reference as we explain the details of each strategy in the rest of this section.

Cohort-sequential (CS) analysis strategy

Developmental scientists often find the cohort-sequential strategy of greatest interest because it explicitly differentiates intraindividual age changes that occur within a cohort from interindividual differences between cohorts. This strategy also permits a check of the consistency of age functions over successive cohorts, thereby offering greater external validity than would be provided by a single-cohort longitudinal design. Cohort-sequential designs are often required to test hypotheses about phenomena assumed to follow the irreversible decrement model of aging, in which a maximal level of functioning is reached at some point in adulthood and thereafter involves linear (or linearly accelerating) and irreversible decrement (Schaie, 1977). The irreversible decrement model of aging is most appropriate for variables on which performance may be dominated by the level of efficiency of the peripheral sensory functions and by psychomotor speed, variables that typically decline with age.

The cohort-sequential strategy requires that at least two cohorts each be assessed for at least two age levels. Thus, as the example in Table 2.2 shows, this strategy requires at least three times of measurement. In other words, to compare the 1920 and 1930 birth cohorts in the example at ages 60 and 70, we would need data that were collected in 1980 (on only the 1920 cohort), in 1990 (on both cohorts), and in 2000 (on only the 1930 cohort).

When using the cohort-sequential analysis strategy, a critical assumption is the absence of time-of-measurement (T) effects on the behavior or variable being studied. This

Table 2.2 Cohort-sequential strategy

	Age at data collection	
Cohort	*60*	*70*
1920 cohort	1980	1990
1930 cohort	1990	2000

assumption may be parsimonious for many psychological variables, but others may still be affected by "true" period effects or by other internal validity threats such as differences in instrumentation or experimenter behavior across test occasions. For example, the terrorist attacks on September 11, 2001 were experienced by most American citizens alive at the time of the event. Variables such as level of anxiety or perceptions of security may vary greatly depending on whether they were measured before or after the event. Yet, other variables, particularly those that depend on physiological development (e.g., grip strength), will be virtually unaffected by period effects. The question arises, then, how violations of the assumption of no time-of-measurement effects would be reflected in the results of the cohort-sequential analysis. Logical analysis suggests that all estimated effects will be perturbed, although the most direct evidence of the violation would be shown in a significant *C* (cohort) by *A* (age) interaction (cf. Schaie, 1973). However, the lack of such an interaction does not necessarily guarantee the absence of *T* effects.

Accelerated longitudinal designs A design proposed by Bell (1953) called the accelerated longitudinal design is also referred to as a cohort-sequential design by some researchers (see, e.g., Duncan et al., 1999; Anderson, 1993, 1995; Duncan, T. E., Duncan, & Hops, 1994; Duncan, S. C., Duncan, & Hops, 1996). However, it should be pointed out that the data generated by the accelerated longitudinal design differ from the data used in Schaie's cohort-sequential strategy. As shown in Table 2.1, the most basic case of Schaie's cohort-sequential strategy requires a minimum of three time points and uses complete information on two ages for two cohorts. In contrast, the accelerated longitudinal design collects data on each cohort at each time point, but not at every age, and thus incorporates missing data into the data matrix by design, as shown in Table 2.3. Under the assumption of no cohort differences, the information from the cohorts in an accelerated longitudinal study is then "linked" to examine an extended developmental trajectory. The convergence of the cohorts' developmental trajectories can be tested, and such tests will be stronger for cohorts with more overlapping time points (Anderson, 1993, 1995; McArdle & Anderson, 1990). Although the data necessary for the cohort-sequential strategy in Table 2.2 can be obtained from Table 2.3 (i.e., the columns for ages 60 and 70), the data generated by the accelerated longitudinal design actually corresponds more closely to the data used by the cross-sequential analysis strategy described next.

Table 2.3 Accelerated longitudinal design

	Age at data collection			
Cohort	*50*	*60*	*70*	*80*
1920 cohort		1980	1990	2000
1930 cohort	1980	1990	2000	

Table 2.4 Cross-sequential strategy

	Year of data collection	
Cohort	*1970*	*2000*
1920 cohort	Age 50	Age 80
1950 cohort	Age 20	Age 50

Cross-sequential (XS) analysis strategy

The basic cross-sequential strategy uses data collected from at least two cohorts at two times of measurement. For example, in Table 2.4, we compare a cohort born in 1920 to a cohort born in 1950 at two time points – 1970 and 2000. This analysis strategy is most appropriate when the variable of interest is expected to be independent of age but not independent of time-of-measurement. For example, we may be interested in how much the sexual attitudes of these cohorts differ in 1970 versus how much these cohorts' attitudes differ in 2000. The assumption that changes in the variable under study are not due to age or change with age at a uniform rate makes it possible to differentiate between cohort (*C*) trends and time-of-measurement (*T*) trends. However, if time-of-measurement effects are slight or nonexistent, the assumption that the variable is independent of age could be examined by estimating age changes (e.g., 20 to 50 and 50 to 80) because the individuals are obviously older at the second time of measurement. In fact, although the focus of the cross-sequential strategy is to contrast cohort differences with changes due to the passage of time, if the data in Table 2.4 were reorganized by age rather than by time, they would be identical to the data collected in the accelerated longitudinal design described in the previous section (Tonry, Ohlin, & Farrington, 1991).

The cross-sequential strategy's assumption that age (*A*) has no effect on the variable of interest may be hard for most developmental researchers to accept. However, this approach may be useful when longitudinal data are available only for a limited number of measurement occasions but extend over a wide range of cohort groupings. For example, suppose that a study was begun in 1970, examining individuals born in the 1910, 1920, 1930, 1940, and 1950 birth cohorts, and a repeated measurement was taken on all individuals in 1980. Despite having conducting her study for 10 years, the researcher cannot yet implement a cohort-sequential analysis strategy to examine age by cohort differences because three measurement occasions are required for that strategy. However, a cross-sequential analysis strategy, requiring only two measurement occasions, could be used in this case. Given a strong developmental theory about the nature of the confounded *A* effects, this strategy can also be used to obtain information about potential *A* effects represented in the *C* and *T* components. For example, if our hypothetical researcher analyzed her data after the second data collection with a 4 cohort × 2 times analysis of variance (ANOVA) and found significant interactions between cohort and time, she could conclude that there were positive age changes for some cohorts and negative age changes for other cohorts. This information could then be examined to obtain an idea of age changes from age 20 to age 80 (also see Schaie, 1996; Schaie & Strother, 1968). Although it is always preferable to estimate parameter effects from the most appropriate design – one that makes the correct limiting assumptions – one must often settle for something less than the optimal, whether this be a temporary expedient or whether dictated by the phenomenon being studied.

Time-sequential (TS) analysis strategy

The time-sequential strategy compares at least two age levels at a minimum of two times of measurement. An example of this strategy is shown in Table 2.5. In this example, a sample of 20-year-olds and a sample of 50-year-olds were drawn in 1970 and new, independent samples of 20-year-olds and 50-year-olds were drawn in 2000. Unlike the prior two analysis strategies that used repeated measures data, this strategy uses all independent samples. In other words, although the 1950 cohort is assessed in both 1970 and 2000, the data are drawn from two different samples from that cohort.

The time-sequential strategy examines whether the difference between the two age groups is the same or different at the two times of measurement. In other words, does the difference between the two age groups remain stable or does it change over time? The difference between 20-year-olds and 50-year-olds may be the same in 2000 as it was in 1970, or it may have narrowed or widened, depending on the variable that is assessed. For example, the difference between 20-year-olds and 50-year-olds in the amount of computer usage is likely to be much greater in 2000 than it was in 1970, while the

Table 2.5 Time-sequential strategy

	Year of data collection	
Age	*1970*	*2000*
20	1950 cohort – S_1	1980 cohort
50	1920 cohort	1950 cohort – S_2

S = Sample.

difference between 20-year-olds and 50-year-olds in how many words can be recalled from a list may be the same in 2000 as it was in 1970.

The time-sequential strategy is most appropriate when one assumes that the behavior being studied follows a decrement with compensation model of aging. In this model, one expects age decrement past maturity, but also allows that significant environmental remediation may compensate for the maturationally programmed deficit. This type of model may be most appropriate for variables such as fluid intelligence and other psychological variables where speed of response is involved. The time-sequential strategy permits the separation of age differences from time-of-measurement differences, assuming only trivial cohort effects.

Assessing Attrition and Practice Effects in Developmental Studies

Campbell and Stanley (1967) described eight different threats to the internal validity of quasi-experiments. One of these, maturation, represents no threat to the validity of developmental studies whose purpose is to test hypotheses about the effects of aging. The remaining seven threats represent rival hypotheses to the effect of aging; these include the effects of history (time), selection (cohort), experimental mortality (attrition), testing (reactivity or practice effects), instrumentation, statistical regression, and certain interactions of these effects. The effects of time and cohort were discussed in the sections above. In the next section, we will review how the three sequential analysis strategies described in the previous section can be extended to combine controls for the effects of time and/or cohort with the assessment of attrition and/or practice effects (see also Schaie, 1988). It must be noted, however, that the most controlled design is not necessarily the best. Implementing such controls can be costly in terms of experimenter efforts and resources and should be done only when absolutely necessary to ensure the integrity of a study.

Attrition effects

In a simple pre-test/post-test design, a cross-sectional attrition analysis can be performed by comparing participants who returned for T_2 to those present at T_1. However, this analysis only addresses how the baseline characteristics of the sample have changed due to attrition and cannot address whether those participants who dropped out would have changed more or less on the dependent variable than the remaining sample, had they remained in the sample. Three or more time points would be necessary to obtain an estimate of the effects of attrition on the measurement of age changes. Also, a simple attrition analysis at T_2 does not account for the possible confounding of attrition with practice or the interaction of attrition with maturation or selection (cohort).

Controlling for time and attrition One way to assess the effects of both time and attrition is to consider two longitudinal samples carried over the same age range: that is, one sample is followed from T_1 to T_2 and a second sample is followed from T_2 to T_3. The members of each sample are then classified according to whether they returned for their second assessment or dropped out (i.e., were only assessed once). The cohort-sequential example that was presented in Table 2.2 can provide a context for this analysis. In the example presented in Table 2.2, the age range of 60 to 70 years was examined for a sample born in 1920 and a sample born in 1930. The 1920 cohort sample was assessed in 1980 (T_1) and 1990 (T_2), while the 1930 cohort sample was assessed in 1990 (T_2) and 2000 (T_3). To examine the effects of time and attrition, a 2 (time of measurement: 1980 or 1990) × 2 (attrition status: returned at age 70 or dropped out) ANOVA could then be performed on the data collected at age 60 for both samples. Because only the first measurement points are considered for either sample in this type of analysis, practice effects are controlled but cohort effects are not controlled.

A more general and interesting format for this analysis uses an extension of the time-sequential strategy and allows the component of variance associated with age to be assessed in addition to the components for time and attrition. This analysis requires obtaining at least one additional data point for each of the independent samples included in the time-sequential analysis. This additional data is only used to classify each individual's attrition status; in other words, this additional assessment point for each sample does not enter into the analysis.

To give an example of this analysis, let us begin with a basic time-sequential strategy comparing 50-year-olds and 60-year-olds at two times in history (1980 and 1990). The four cells marked "$R + D$" in Table 2.6 represent the four samples used in a basic time-sequential strategy assessing time and age. To extend this example to also assess attrition, as many individuals as possible are retrieved from the two samples first assessed in 1980 and are reassessed in 1990 (i.e., at age 60 for Sample 1 from the 1930 cohort and at age 70 for the sample from the 1920 cohort sample), and as many individuals as possible from the two samples first assessed in 1990 would be reassessed in 2000 (i.e., at age 60 for the sample from the 1940 cohort and at age 70 for Sample 2 from the 1930 cohort). This additional data is used only to classify the individuals in the original four samples as having returned (R) or having dropped out of the study after the first assessment (D).

Table 2.6 Extension of the time-sequential strategy to assess time × attrition

Time of test	*Age*		
	50	*60*	*70*
1980	1930 cohort – S_1 ($R + D$)	1920 cohort ($R + D$)	
1990	1940 cohort ($R + D$)	1930 cohort – S_2 ($R + D$)	
2000		1930 cohort – S_1 (R*) 1940 cohort (R*)	1920 cohort (R*) 1930 cohort – S_2 (R*)

S = Sample; R = returned for second assessment; D = dropped out after first assessment.
*This data is used only to classify individuals as those who returned or dropped out and does not enter into the analysis.

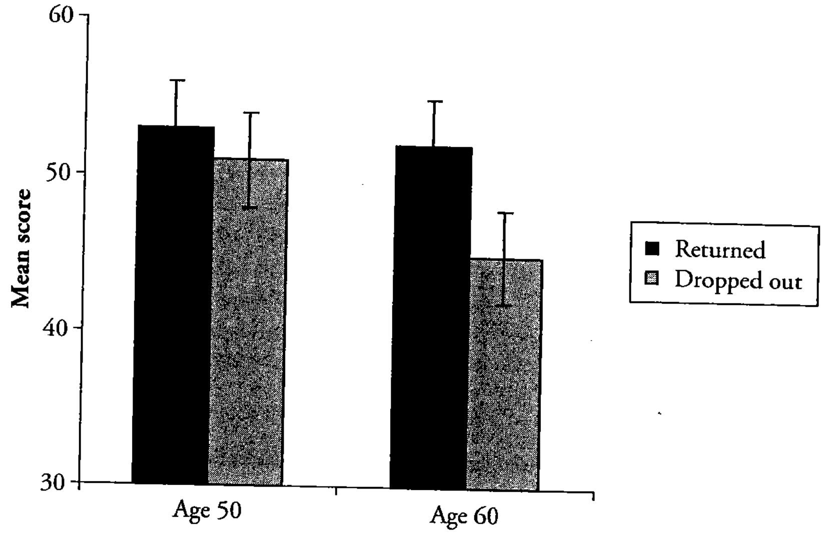

Figure 2.2 Example of an age × attrition interaction.

The ANOVA framework would again be used for this analysis, now using a 2 (age: 50 or 60) × 2 (time of test: 1980 or 1990) × 2 (attrition status: returned or dropped out) design. The attrition status main effect and its interactions with age and time provide information about the differential patterns of attrition by age and by time. For example, if a significant main effect were found for attrition, one possible conclusion is that the sample that returned had higher scores on average than those who dropped out. On the other hand, if a significant interaction for age by attrition such as that shown in Figure 2.2 were found, one could conclude that, of the sample measured at age 60, those who returned were likely to have higher scores than those who dropped out while no such difference was found for the sample measured at age 50.

Controlling for cohort and attrition Extending the standard cohort-sequential design allows attrition effects to be crossed with cohort and age. Table 2.7 extends the cohort-sequential example in Table 2.2. An additional assessment of each of the two cohort samples at a third age (i.e., age 80) would be added to the original cohort-sequential design. Specifically, the 1920 cohort sample would again be assessed in 2000 at age 80, and the 1930 cohort sample would be assessed in 2010 at age 80. This final assessment of both samples at age 80 would be for the purpose of identifying dropouts only and would not enter into the analysis. The analysis of age, cohort, and attrition is performed for all individuals who were measured twice ($R + D_2$) as a repeated measures ANOVA (i.e., 2 age (repeated) × 2 cohort × 2 attrition status [R versus D_2]). A significant age × attrition interaction would provide evidence of differential age changes on the dependent variable for the group that returned versus the group that dropped out.

An alternative analysis method for examining age, cohort, and attrition involves extending the independent samples variant of the cohort-sequential analysis strategy. In the independent samples variant, an independent sample is drawn from each cohort

Table 2.7 Repeated measures extension of the cohort-sequential strategy to assess cohort × attrition

	Age at data collection		
Cohort	*60*	*70*	*80*
1920 cohort	1980 ($R + D_1^* + D_2$)	1990 ($R + D_2$)	2000 (R^*)
1930 cohort	1990 ($R + D_1^* + D_2$)	2000 ($R + D_2$)	2010 (R^*)

R = Returned for second and third assessment; D = dropped out after first assessment.
*This data is used only to classify individuals' attrition status and does not enter into the analysis.

Table 2.8 Independent samples extension of the cohort-sequential design to assess cohort × attrition

	Age at data collection		
Cohort	*60*	*70*	*80*
1920 cohort	C_1S_1 ($R + D$)	C_1S_2 ($R + D$) C_1S_1 (R^*)	C_1S_2 (R^*)
1930 cohort	C_2S_1 ($R + D$)	C_2S_2 ($R + D$) C_2S_1 (R^*)	C_2S_2 (R^*)

C = Cohort; S = sample; R = returned for second assessment; D = dropped out after first assessment.
*This data is used only to classify individuals as those who returned or dropped out and does not enter into the analysis.

at each age studied, rather than repeatedly assessing the one sample drawn from each cohort. In Table 2.8, the four samples that would be included in the independent samples variant of the basic cohort-sequential strategy are marked "$R + D$." To include an assessment of attrition effects, a repeated measurement would be added for each of these four samples at the next time point. This additional data (marked R^*) is only used to assign the attrition status and does not enter into the analysis. The analysis is performed as a 2 (age: 60 or 70) × 2 (cohort: 1920 or 1930) × 2 (attrition status: returned or dropped out) ANOVA. In this analysis, a significant interaction of age and attrition indicates that the difference between the group that returned and the group that dropped out varied based on whether the group was measured at age 60 or age 70.

Controlling for time, cohort, and attrition It is also possible to specify analysis designs that allow the crossing of attrition effects with both time and cohort. These designs involve extensions of the cross-sequential strategy. Table 2.9 demonstrates that an additional measurement point would be necessary to determine dropouts following the second

Table 2.9 Repeated measures extension of the cross-sequential strategy to assess cohort × time × attrition

Time of test	*Cohort birth year* *1920*	*1930*
1980	Age 60 ($R + D_1^* + D_2$)	Age 50 ($R + D_1^* + D_2$)
1990	Age 70 ($R + D_2$)	Age 60 ($R + D_2$)
2000	Age 80 (R^*)	Age 70 (R^*)

R = Returned for the second and third assessments; D_1 = dropped out after the first assessment; D_2 = dropped out after the second assessment.

*This data is used only to classify individuals as those who returned or dropped out and does not enter into the analysis.

Table 2.10 Independent samples extension of the cross-sequential strategy to assess cohort × time × attrition

Time of test	*Cohort birth year* *1920*	*1930*
1980	C_1S_1 ($R + D$)	C_2S_1 ($R + D$)
1990	C_1S_2 ($R + D$)	C_2S_2 ($R + D$)
	C_1S_1 (R^*)	C_2S_1 (R^*)
2000	C_1S_2 (R^*)	C_2S_2 (R^*)

C = Cohort; S = sample; R = returned for second assessment; D = dropped out after first assessment.

*This data is used only to classify individuals as those who returned or dropped out and does not enter into the analysis.

assessment. The repeated measures design requires classification into dropouts and survivors after the first and second assessments. Attrition at the second time point consequently is confounded with practice effects. The analysis of time, cohort, and attrition is performed for individuals who were measured twice ($R + D_2$) as a 2 (time, repeated) × 2 cohort × 2 attrition status repeated measures ANOVA.

If independent samples from each cohort are used instead of repeated measurements on the same cohort samples, practice effects are now controlled for, but each independent sample must be assessed twice for each level of the design. In Table 2.10, the four samples that would comprise the basic cross-sequential strategy with independent samples are marked "$R + D$." The data from the reassessment of each of these four samples at the next time point is used only to determine attrition status. The analysis can be performed as a 2 (time: 1980 or 1990) × 2 (cohort: 1920 or 1930) × 2 (attrition status: returned or dropped out) ANOVA.

Practice effects

The possible inflation of longitudinal change estimates because of practice effects can be studied by comparing individuals at the same age who are retest returnees with the performance of individuals assessed for the first time at T_2. However, such a comparison involves the comparison of an attrited sample with a random sample. The mean values for the longitudinal group should therefore be adjusted for attrition to permit a valid comparison. The appropriate adjustment is the difference between returnees and the entire sample at baseline (rather than the difference between returnees and dropouts). Similar analyses can be conducted to assess the continuing effect of practice at additional assessment points in the study.

Controlling for time and practice The effects of time and practice for a particular age level can be examined with a minimum of four independent samples and three measurement occasions. Data collected at T_2 or T_3 are compared for samples of equivalent age that were either assessed at the previous time point or that are assessed at T_2 or T_3 for the first time. Returning to the cohort-sequential example in Table 2.2 where a sample from each of two cohorts was assessed at ages 60 and 70, suppose that another sample from each of the two cohorts had been drawn and only measured at the second age studied (i.e., age 70). Then, the two original samples (measured twice) are the "practiced" groups at age 70, and the two new samples are the "unpracticed" groups. An analysis of the data collected at age 70 contrasts time of measurement with practice. Cohort is confounded with time of measurement in this analysis in that all of the data collected in 1990 (i.e., T_2) was from the 1920 cohort and all of the data collected in 2000 (T_3) was from the 1930 cohort.

A more general formulation of this analysis that balances ages at pre-test is an extension of the time-sequential strategy that also crosses age with time, and practice. An example of this analysis strategy is shown in Table 2.11. The four starred samples represent the basic data required in a time-sequential design. These four samples are retested at the next time point, creating the practiced groups. At the retest time points,

Table 2.11 Extension of the time-sequential strategy to assess age × time × practice

Time of test	*Age at data collection*		
	50	*60*	*70*
1980	1930 cohort – S_1^*	1920 cohort – S_1^*	
1990	1940 cohort – S_1^*	1930 cohort – S_2^*	
2000		1930 cohort – S_1 (*P*)	1920 cohort – S_1 (*P*)
		1930 cohort – S_3 (*U*)	1920 cohort – S_2 (*U*)
		1940 cohort – S_1 (*P*)	1930 cohort – S_2 (*P*)
		1940 cohort – S_2 (*U*)	1930 cohort – S_4 (*U*)

S = Sample; *P* = practiced; *U* = unpracticed.

*This data does not enter into the analysis but is required to establish differential levels of practice.

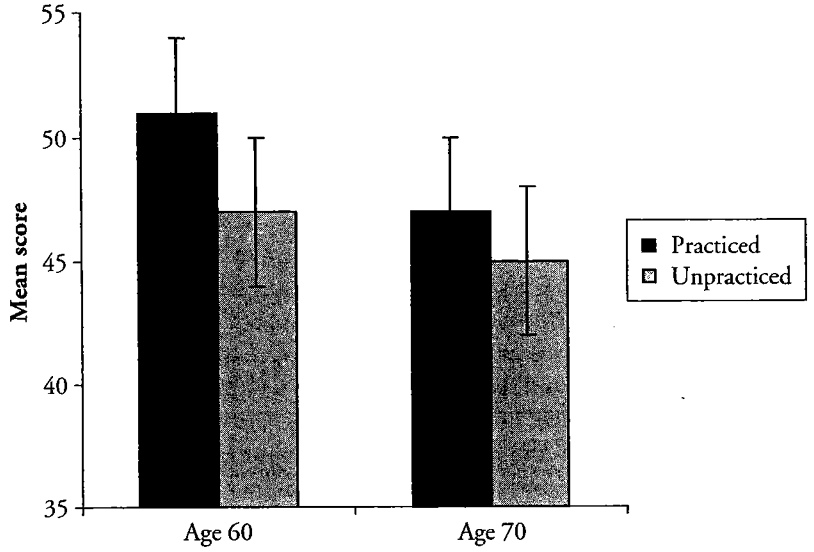

Figure 2.3 Example of an age × practice interaction.

four new (unpracticed) samples are drawn and tested. Thus, the data used for this analysis comes from at least eight samples (four at each of two age levels), half of which are pre-tested at an earlier occasion before generating the data that enter into this analysis.

The analysis can then be performed as a 2 (time: 1990 or 2000) × 2 (age: 60 or 70) × 2 (practice level: practiced or unpracticed) ANOVA. A significant main effect for practice might demonstrate that those who had been pre-tested showed significantly higher levels of performance at retest than those who were first tested, regardless of age or time of measurement. A significant age × practice effect would reflect age-specific practice effects. Figure 2.3 shows an example of such an interaction where practice has greatly increased the performance of the 60-year-olds but only had minimal benefit for the 70-year-olds. It should be noted that this analysis confounds practice with attrition. The implication of this confound is that the practiced sample is also an attrited sample.

Controlling for cohort and practice The cohort-sequential design with independent measurements can be expanded to permit crossing of age, cohort, and practice. A minimum of two samples is required at each age level for each cohort, half of whom have received practice at a previous data point that does not enter the analysis. Consequently, a minimum of four assessment points will be required for this design, which also confounds practice with attrition.

The four starred assessments in Table 2.12 represent the four original sets of data used in the basic independent samples variant of the cohort-sequential strategy. Each of these four samples is retested at the next time point; at each retest point, a new independent sample is also drawn from each cohort and tested for the first time. The analysis of cohort, practice, and age can be performed as a 2 (age: 70 or 80) × 2 (cohort: 1920 or 1930) × 2 (practice status: practiced or unpracticed) ANOVA. A significant cohort

Table 2.12 Independent samples extension of the cohort-sequential design to assess cohort × practice

Cohort	*Age at data collection* *60*	*70*	*80*
1920 cohort	$C_1S_1^*$	$C_1S_2^*$ C_1S_1 (P) C_1S_3 (U)	C_1S_2 (P) C_1S_4 (U)
1930 cohort	$C_2S_1^*$	$C_2S_2^*$ C_2S_1 (P) C_2S_3 (U)	C_2S_2 (P) C_2S_4 (U)

C = Cohort; S = sample; T = time; P = practiced; U = unpracticed.
*This data does not enter into the analysis but is required to establish differential levels of practice.

× practice interaction indicates that the effect of practice on the dependent variable differed by cohort.

Controlling for time, cohort, and practice Once again, for those adult age levels when age effects can be assumed to be trivial, it would be possible to cross time, cohort, and practice by extending the cross-sequential design with independent measurements. The minimum design here would require three assessment points. That is, each of the four possible cohort/time-of-measurement combinations (at T_2 and T_3) would require two samples, one of which received practice at T_1 or T_2. Table 2.13 provides an example of the data necessary to perform the 2 (time: 1990 or 2000) × 2 (cohort: 1920 or 1930) × 2 (practice status: practiced or unpracticed) ANOVA to examine the components of time, cohort, and practice.

Table 2.13 Independent samples extension of the cross-sequential design to assess time × cohort × practice

Time of test	*Cohort birth year* *1920*	*1930*
1980	Age 60 – $C_1S_1^*$	Age 50 – $C_2S_1^*$
1990	Age 70 – $C_1S_2^*$ Age 70 – C_1S_1 (P) Age 70 – C_1S_3 (U)	Age 60 – $C_2S_2^*$ Age 60 – C_2S_1 (P) Age 60 – C_2S_3 (U)
2000	Age 80 – C_1S_2 (P) Age 80 – C_1S_4 (U)	Age 70 – C_2S_2 (P) Age 70 – C_2S_4 (U)

C = Cohort; S = sample; T = time; P = practiced; U = unpracticed.
*This data does not enter into the analysis but is required to establish differential levels of practice.

Designs crossing practice and attrition

Using the independent measurement designs allowed the effects of attrition to be assessed while controlling for practice. The converse approach (assessing the effects of practice while controlling for attrition) is not feasible because study participants returning for a second assessment represent, by definition, only the group of retest survivors. It is possible, however, to cross attrition and practice if, rather than comparing only those who returned and those who dropped out after T_1, we also consider dropout after T_2. In this case, a prior occasion of data not entering the analysis would be required for half of our groups, and all individuals must be followed to the occasion beyond the last analysis point, to determine dropouts and survivors for each subset. All the designs described can be treated in this manner, but an additional assessment occasion is required. Thus, designs crossing practice and attrition with either cohort or time will require four assessment occasions. The design that crosses attrition and practice with both cohort and time will require a minimum of five occasions.

Summary

The study of adult development has benefited markedly from shifts in methodological paradigms as well as from the application of innovative methods particularly suited to the study of behaviors occurring across age and time. In this chapter, we first focused on the need to determine whether the investigator is interested in age differences or age changes. We then discussed multiple observation analysis strategies suitable for distinguishing the effects of age, cohort, and time of measurement. To review, the cohort-sequential strategy contrasts cohort with age; the cross-sequential strategy contrasts age with time; and the time-sequential strategy contrasts time with age. Finally, we discussed controlling threats to the internal validity of studies. We showed how the basic analysis strategies can be extended to provide assessments of practice and attrition in addition to the effects of age, cohort, and time.

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