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# Beyond Calendar Definitions of Age, Time, and Cohort: The General Developmental Model Revisited

K. WARNER SCHAIE

*The Pennsylvania State University*

K. W Schaie's 1965 (*Psychological Bulletin*, 64, 91–107) general developmental model was designed to explicate research strategies that permit the separation of age, cohort, and period (time-of-measurement) effects. Because of the dependency of each one of these constructs upon the remaining two, it has been necessary to impose restrictive assumptions to permit unconfounding of sources of developmental influences. This paper examines conditions under which the parameters of cohort and period can be freed from their dependency upon calendar time. Expanded definitions, thought to have increased explanatory power, are offered for the concepts of cohort and time-of-measurement. Implications for developmental research that might employ sequential strategies are examined, and future directions for the measurement of developmental context are sketched. 

Some two decades ago, at the 1964 meeting of the American Psychological Association, I first presented my thinking on the relationship between developmental data collected via the cross-sectional and longitudinal methods, by describing a general developmental model from which the two approaches could be derived as special cases together with a third approach which I named time lag. That paper and the publications resulting therefrom (Schaie, 1965, 1967) received wide attention. In particular, it appeared that the more general sequential methods which I had suggested as extensions derivable from the general model offered the hope of unconfounding the age and cohort variance present in cross-sectional data as well as the confounded age and period (time-of-measurement) variance found in longitudinal studies.

What I had tried to make clear, however, from the very beginning was the fact that the three parameters defining the model (age, time, and cohort) could not be estimated simultaneously; that is, given information on any two parameters, the third would be determined. Unconfounding the

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effects of any two parameters therefore required the assumption that the third parameter was either zero or of trivial magnitude. Although it is possible to use the sequential methods when this assumption is violated, the comparison of any set of two sequential effects will then be confounded with the third effect.

Models that contain parameters, one of which is wholly determined by the others, are well known in science (e.g., the attributes of volume, pressure, and temperature in physics). Just as in the case of confounded physical parameters, there are many reasons why one would want to examine the relative contributions of any of the three possible sets of two developmental parameters. While it is true that developmental psychologists may be most interested in an age × cohort matrix (cf. Schaie & Baltes, 1975), other social scientists may find age × time or time × cohort matrices to be more informative.

In the original 1965 paper, some intuitive decision rules were offered (modified in Schaie, 1970) that were thought to be helpful to the researcher who did not have strong empirical or theoretical grounds for deciding which of the three parameters should be set to zero. These rules are problematic, however, because their use requires equal time and cohort intervals (Adam, 1977; Botwinick & Arenberg, 1976), and since they fail to distinguish between several different model assumptions (Adam, 1978; Buss, 1973). These rules were therefore abandoned in favor of making explicit model assumptions by specifying the side conditions appropriate for a given substantive problem (cf. Schaie, 1973a; Schaie & Hertzog, 1982).

The recent literature on the analysis of sequential data matrices would finesse the problem of invalid parametric assumptions by promoting regression models that estimate simultaneously the effects of age, period, and cohort under an additivity assumption that allows for no interaction among the factors (e.g. Buss, 1979/1980; George, Siegler, & Okun, 1981; Horn & McArdle, 1980; Mason, Mason, Winsborough, & Poole, 1973; Winsborough, Duncan, & Read, 1983). Interaction effects could obviously be modeled as well. The reason that this has not been done, however, is quite instructive. When categorical dummy variables are used, it is then no longer possible to distinguish the interaction effects of two variables from the main effects of the third. Regression models for the study of sequential data sets do represent a step forward in the modeling of average developmental functions by employing sophisticated applications of the general linear model. They are prone to errors of inference, nevertheless, whenever the assumption of additivity or other parametric assumptions needed to identify the model are violated (Glenn, 1976). For example, Glenn (1981) has shown how the additive approach can lead to cumulative errors when all effects from two or more of the three factors are monotonically ordered in a given study.

In spite of these problems there have been a number of interesting studies in the literature that have made good use of one or another sequential design by consciously misspecifying the necessary assumptions. That is, such studies have set to zero that parameter that was either of least interest, or on empirical and logical grounds least likely to account for much variance (e.g., Costa & McCrae, 1982; Douglas & Arenberg, 1978; George et al., 1981; Palmore, 1978; Schaie, 1983; Schaie & Hertzog, 1983; Schaie & Parham, 1976, 1977). None of these efforts, however, satisfied the original objective of providing unambiguous estimates of the variance accounted for by each of the individual components of developmental change. The conclusion must now be reached, then, that a solution of a purely statistical nature may not be available (also cf. Hertzog & Schaie, in press; Schaie & Hertzog, 1982). An alternative approach is needed, therefore, that would reorient our thinking and suggest a possible way out of what has become a methodological impasse.

Much of the concern with methodologies designed to separate age, cohort, and period effects has arisen from our preoccupation with the role of age as the independent variable of prime interest to developmentalists. In this article, it is shown that cohort and period may have more interesting explanatory properties than age. We begin this analysis by examining the role of context in the study of life-span development. Second, we examine in some detail how cohort effects and historical time can be conceptually separated from calendar time (cf. Schaie, 1984). Third, an approach is presented to a possible reformulation of the general developmental model, given indicators freed from restrictions which have thus far been accepted as virtually immutable. In this approach, chronological age, or other age functions related to calendar time, rather than serving as explanatory concepts, emerge as useful scalars, that indicate to us the amount of time elapsed within the life of individuals over which developmental phenomena have occurred.

## THE ROLE OF CONTEXT IN LIFE-SPAN DEVELOPMENT

One of the major contributions of the life-span psychology movement has been the shift from a search for purely "developmental" patterns of a normative nature to a concern with the context within which development occurs. Of particular importance here is the contention that context is not simply confined to an ecology of situation, place and culture a la Bronfenbrenner (1977), but that the specific historical period during which development occurs must be explicitly included as a major parameter.

Concern with the effect of historical periods upon development has emerged largely from the study of adults. There are good reasons why this should be so. Children might reasonably be expected to possess at least some behavioral characteristics that ought to be constant across historical time, if only because of the imperative need to establish behavioral competencies essential for survival (Kagan, 1980). Survival-relevant behaviors might once again merit concern for the study of advanced old age. But few, if any, such behaviors seem important for the course of development during much of adulthood. For those variables where a behavioral asymptote is reached in young adulthood or middle age, therefore, it becomes necessary to consider influences other than those related to chronological age, in order to account for individual differences in developmental change for much of adult life. The developmental scientist interested in the study of individual differences in adulthood, therefore, must become increasingly interested in those sources of variance that are usually referred to as cohort and period effects (cf. Schaie, 1973a, 1977).



The concern with the context in which development occurs arose originally in a manner similar to the efforts of early experimental psychologists who wished to control for individual differences because they were perceived to be major sources of unwanted error variance. That is, in the past developmental scientists have often viewed cohort and period effects as confounds that are best controlled and where possible explained away as experimental artifacts. Rosow (1978) was thus able to argue with some justification that the early work on sequential strategies (e.g., Baltes, 1968; Schaie, 1965) treated effects other than age as nuisances, or at best as sources of incidental information. It is difficult, however, to advocate greater research priorities for the study of these effects as long as they remain mere indices that account for an otherwise unexplained proportion of variance in the dependent variable. When used in this manner, cohort and period are equally empty constructs and subject to the same objections as those raised earlier with respect to chronological age (Schaie & Hertzog, 1985; Wohlwill, 1973). A step forward can be taken, however, by sketching a framework that orders historical context in terms that should have explanatory value for developmental psychologists. To do so effectively, it is necessary to broaden the concepts of cohort and period. It is also necessary to entertain methods for scaling the possible impact of historical events upon behavioral phenomena, and to contemplate ways in which individual differences in position on space–time templates for diverse attributes might be related to chronological age.

## COHORT AS A SELECTION VARIABLE

Developmental psychologists have thus far utilized the cohort concept primarily as a way of organizing groups of individuals by their birth year. I have recently tried to broaden that use by defining cohort as "the total population of individuals entering the specified environment at the same point in time" (Schaie & Hertzog, 1982, p. 92). It should be explicitly noted, however, that the point of common entry need not necessarily be birth and that there are many other ways in which individuals can enter a specified environment under study (see Figure 1).[1]

A classification scheme developed by Baltes and his associates (Baltes, Cornelius, & Nesselroade, 1979) for the various types of influences impacting human development may be helpful also to characterize the different ways in which cohorts may be formed. They classified these developmental influences into three basic types: age-graded, history-graded and nonnormative. Samples selected in terms of the first of these influences would be almost (but not entirely) as homogeneous by age as would result from selection by birth year alone. Examples of age-graded cohort definers (in declining order of presumed correlation with chronological age) would be entry into the public school system, menarche, birth of first child, becoming a grandparent, retirement, and death. Note that these cohort definers include life events that are biologically as well as societally programmed. What these definers have in common is the attribute of being essentially *normative* in nature. Even those influences that are programmed by societal norms are still constrained by relevant biological characteristics ordered by age.

Other possible cohort definers may be quite randomly distributed in

[1] For alternate but related conceptualizations of these issues see Nesselroade (1983), Nydegger (1981), Rosow (1978), and Slife (1981).

| Age-graded cohorts | |
|---|---|
| Biological | Societal |
| Menarche | School entry |
| Menopause | Enlistment |
| First child | First marriage |
| Grandparenthood | Retirement |
| Death | |

History-graded cohorts

Initial staff of new college or corporation
"Class" entering ranks of unemployed
Class of technical or proprietary school
Conscripts called up in a general mobilization

Nonnormative cohorts

Divorce
Infectious disease
Disabling condition
Membership in social group

FIG. 1. Examples of alternative cohort definers.



the population with respect to age, at least over the broad range of middle adulthood. Such definers are likely to be history-graded influences which form cohorts defined by events such as the staffing of a new college or corporation, the induction of conscripts in a general mobilization, those entering the ranks of the unemployed during a recession or depression, or during periods of rapid technological change, and those who enter a given class of a technical or proprietary school (cf. also Hannan & Freeman, 1977).

Cohorts can also be formed by the common experience of certain nonnormative events. Nonnormative events, for this purpose, may be defined as those favorable events that are not essential for the adequate development or survival of all (or even most) persons, and/or the unfavorable events which may affect some persons' development but that may be avoidable for many individuals. The temporally close experience of such nonnormative events, then, can result in the formation of definable cohort groupings. Obviously these cohort definers are generally uncorrelated or at most moderately correlated with calendar age. Examples of nonnormative cohort definers would include divorce, experience of an infectious disease, onset of a disabling condition, membership in a particular social group, purchase of a home in a particular neighborhood, and so on. In fact, cohorts of this type can be formed by the specification of common times of initial attainment, loss or duration of class membership for any identifiable nonnormative demographic characteristic.

It is important to note that equal-interval boundaries may not be reasonable, or may be possible only for some of the above-described cohort groupings. Further, assignment of all individuals to cohorts representing different levels of a given influence is possible only for some of the biologically determined age-graded influences. Nevertheless, assignment to cohorts defined by influences holding only for limited subpopulations may actually yield more powerful predictions in individual cases than is possible from knowledge of their standing on universally defined characteristics.

## PERIODS AS DISCRETE EVENTS

In the above section it was suggested that it is possible to generate cohort definitions which can be uncoupled from chronological age. In a similar manner, it may be possible to uncouple the concept of period from its current identity with specific calendar dates. To do this it is necessary to convert the status of the time-of-measurement construct from an index variable to an explanatory concept. We begin by noting that it is the nature of the particular historical event or events that lends meaning to its occurrence rather than its particular calendar date. This formulation was first introduced by Sorokin and Merton as long ago as 1937, but it has received little attention thus far, particularly for the study of development. As was true for the analyses of alternate cohort definers, some organizational principles are needed also to classify expanded definers of the period concept. The definers proposed for cohorts, unfortunately, will not work here because period effects are history-graded by definition.

An alternate classification scheme might be provided by attending to the range of impact of history-graded events. Some events do have universal impact, such as major wars, or the introduction of technological changes that achieve virtually instantaneous and universal acceptance. Other events are far more parochial in nature and affect only certain localities or specific subsets of the general population. They may be cohort-specific under the new and broadened definition offered above. Of further concern is the fact that all events, whether general or specific, may impact different localities or even different individuals at different points in time.

Our earlier definition of time of measurement, as "the point in time at which the response of interest is recorded (Schaie & Hertzog, 1982, p. 92)" thus no longer suffices. What is now needed is a designation of the calendar date at which a particular historical event has had the opportunity to impact a specified proportion of the target population. For the most intensive study of individual development, moreover, it would be necessary to assign to each individual a period index for each developmentally influential event under study that would designate when such influence could have impacted the target person. As a corollary an indicator might be designated, of course, that would reflect the temporal cessation of the event's impact.

Critical to the utilization of a broadened period concept is the identification of historical events that may be presumed to have developmental impact during the life course of subjects under study and scaling the temporal position of greatest impact (or duration of impact) of such events. Two separate problems are implicit in such an approach. The first is concerned with the identification of what kind of events are likely to have impact upon development. Here we can lean upon the substantive work of developmentalists interested in the contextual aspects of life events (e.g., Brim & Ryff, 1980; Hultsch & Plemons, 1979; Lerner, 1985). The second issue, that of identifying the temporal position of such events, has received some attention in the sociological literature, particularly in the context of treating individual development as a population process (e.g., Allison, 1982; Featherman, 1985, 1986; Tuma, 1982; Tuma, Hannan, & Groenveld, 1979). Formal models of analysis for event history analysis have recently been described by Hogan (1984). Our objective, however, is not to aggregate events in a manner that could result in an alternative definition for chronological age akin to some of the earlier proposals for a social age index (cf. Johnston & Hoover, 1982; Neugarten & Datan, 1973). What is needed, instead, is to create an appropriate set of new indicators required for the operationalization of the period (time-of-measurement) construct as defined above.



## MEASURING HISTORICAL EVENT TIME

To obtain the desired indicators for the redefined period construct, it will be necessary to conduct a critical analysis of modern history texts, while minding the findings of the life event literature, in order to create a taxonomy of development-relevant historical events. Professional raters can then be used to classify these events vis-à-vis their relevance to specific behavioral domains. Standard multiple discriminant scaling techniques applied to ratings of similarity can then be used to cluster events and reduce the large number that could be studied to more manageable and representative proportions. The process to be envisaged is like that which led eventually, from the original taxonomy of behavior relevant trait names conducted by Allport and Odbert in 1936, to more modern strategies for the definition and measurement of the trait domain (e.g., Cattell, 1957; Nesselroade & Bartsch, 1977).

Once a workable number of discrete events has been selected and their dimensions have been identified, it will then be necessary to conduct a further search of the historical literature to obtain temporal anchor points that can be used as the quantitative base for the new period indices. Specifically, we would note the calendar date of first possible impact of a given event, as well as the date at which such impact had become universal for the target population under study. A prudent approach might be to define relatively conservative boundaries, such as the year when at least 10% of the population had adopted a technological innovation (e.g., the automobile, the telephone, or television) or accepted a changed custom or attitude (e.g., integration of public schools, jogging, or minidresses) and that year when 90% of the population had become impacted by the change event. Event impact, however, is not necessarily unidirectional and can have forms other than linear progression from its inception to its universal impact. Thus we might also consider a criterion of an event having ceased to have impact when less than 10% of the target population remains affected. Figure 2 provides some rough schemata for examples of events with different patterns of impact.

No historical event impacts behavior in isolation, and the relative impact value of events occurring during the same or overlapping temporal intervals must be assessed. When concurrent behavioral measurements are available on individuals together with information on individual experiences of the targeted historical events, it might then be possible to as-

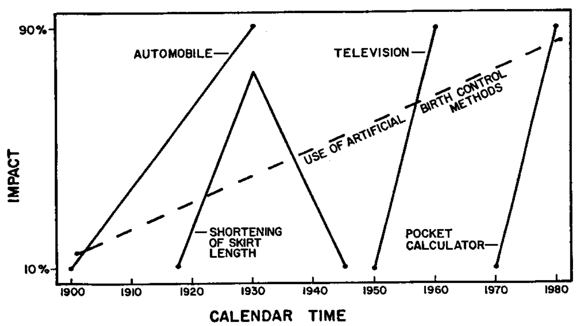


FIG. 2. Period as event time [Reproduced, by permission of the publisher, from Schaie (1984)].

sess the relative importance of different events (or differential individual experiences of the same event) directly by means of appropriate regression analyses. In the absence of the requisite data base, it might still be possible to obtain the needed parameters by means of expert judgment. Once this is done, calendar time can then be rescaled in terms of historical event impact density.

Given a schema of multidimensional event classifications, it would be possible to substitute alternative time frames that have greater explanatory power for the conceptually empty calendar period. For example, there might be one event-density-based calendar for technological change, another for health-relevant interventions, a third for sexual mores, a fourth for the rate of information acquisition, and yet another for events enhancing self-awareness.

The broadened approach to the concept of time-of-measurement (period) as a set of events marking different dimensions of events occurring in historical time requires attention to a number of event characteristics that have received some attention in the sociological literature (cf. Allison, 1982; Featherman, 1985; Zerubabel, 1981) but that heretofore have been largely ignored by psychologists. Five classes of event attributes, with nonexclusive examples of relevant dimensions, are summarized in Fig. 3.

The first attribute is concerned with the type or content of a given event. As noted above, taxonomic studies are needed to provide event content domains that would justify the establishment of distinct event calendars. The second attribute concerns the manner in which event impact is defined. In addition to the convenient population definition offered here, it may also be necessary to provide content-specific definitions for impact upon individuals. Because of the multidirectionality of



Type of event
- Technological
- Attitudinal
- Personal habits
- Knowledge diffusing

Impact of event
- Initial occurrence
- Universal recognition
- Dissipation

Direction of impact
- Linear
- Recursive

Event density
- Population effects
- Individual effects

Perception of event
- Objectively defined by professional judges
- Subjectively perceived by individual under study

FIG. 3. Attributes of events that mark noncalendar time.

developmental events for populations as well as individuals (cf. Baltes & Willis, 1977), it might be surmised that linear models of event time would at best offer first approximations, of little validity in many cases. The third event attribute therefore involves the specification of the mathematical model to be fitted to the direction of impact. The fourth attribute is concerned with the event density experienced for given periods of calendar time. Here individual and population effects must obviously be distinguished, with due attention given to the event domains over which event density is to be aggregated. Finally, as with any psychological variable, it is possible to distinguish alternate perceptions of events: those objectively defined by professional judges, those determined by population surveys, or those subjectively perceived by individuals known to be impacted by the events.

Attention to these event attributes, and their inclusion in the operations that were suggested for the rescaling of calendar time, will ensure that the new indicators that temporally delineate a developmental sequence will have psychological meaning. A move from the previous enslavement to a purely physical time dimension to a time frame that has greater existential meaning might have the surplus value of bridging some of the current ideological gaps between developmentalists committed to a hard-nosed experimental approach and those who would take a more humanistic stance towards life-span development (cf. Neugarten & Datan, 1973; Schaie, 1973b; Sparks, 1973). It should be stressed, however, that the approach advocated here does not seek to substitute a purely subjective calendar for real time. The objective of our redefinition is to suggest that historical time ought to be redefined quite objectively in terms of event density. That is, time employed as the independent variable is to be scaled such that periods of time that are filled with behavior-relevant events will count more than other periods that are relatively devoid of such events.

Event time parameters estimated for populations would explicitly be substituted for the conventionally used calendar times-of-measurement (periods). That is, equal intervals between successive assessment points might be chosen in terms of equal event density and consequently unequal calendar times. Likewise, intraindividual comparisons might be made in equal event time units, and such units would be equally attractive as scalars for the dependent variables of interest. In sum, it is contended, then, that the new event time units, given their more explicit psychological meaning, will move us away from time as a surrogate but empty index variable. These units ought to correspond much more closely to changes in the variables of interest to developmentalists than would age and calendar time, with a concomitant increase in predictive potency and explanatory power.

## IMPLICATIONS FOR A REDEFINITION OF THE GENERAL DEVELOPMENTAL MODEL

Thus far some redefinitions have been offered for the currently used terminology, and initial steps were suggested that would permit operationalizing these components of developmental change in their new form. It now remains to consider possible implications for a redefinition of the General Developmental Model and to examine how the redefinitions of the components of developmental change proposed in this article would affect the estimation of age, cohort and period effects. As an orientation to this topic, it is first shown how our reconceptualization helps to distinguish more clearly between cohort and period effects.

### *Distinguishing Features of Cohort and Period*

Broadening of the concepts of cohort and period calls attention to a rather important difference between the two. This difference refers to the fact that cohort as a selection variable clearly must be and can only be an interindividual difference variable. The broadened definition of cohort makes it possible to assign persons simultaneously to be members of two or more temporally distinct cohort classifications. For example, it is possible, at the same time, to be a member of the initial (oldest) group of residents in a subdivision and to be a member of the most recent (experientially youngest) group of initiates in a social club. Nevertheless, there simply is no way in which one can belong to two cohort levels on the same selection variable.



By contrast, period effects, whether calendar or event time, whether short or long, must be in the nature of intraindividual change, or population aggregate estimates thereof. Period effects imply a duration, a beginning, and an end point that do not occur simultaneously in time. What is possible and quite likely, however, is that two different individuals coexisting during the same calendar time period will experience the same events on a different time scale, or experience different events at the same point in time. This is precisely why we introduced the concept of event time.

### *Implications for the Estimation of Pure Age Effects*

The salient distinction between cohort and period made above sheds further light on the interrelation between cross-sectional and longitudinal data. It clarifies the fact that chronological age has the status of an interindividual difference variable in cross-sectional data, but that of an intraindividual change variable in longitudinal data. It might, of course, be argued that age in both instances may have the status of a temporal selection variable (cf. Nesselroade, 1983). Nevertheless, whatever it is that is held in common by the two age indicators must be other than cohort membership (now defined as a multiple set of selection criteria) or experience of historical events (now considered as event time density). What then is left for the concept of age per se? Here it may be necessary to return to a rather restrictive maturational view. Pure age effects, when extricated from cohort and period confounds, should thus reflect age-graded phenomena that are strictly species-specific, biological, and/or ethological in nature. All other variance will be accounted for by group membership (multiply defined) and the experience of history-graded events. Featherman (1985, 1986) has argued, therefore, that pure aging effects should be conceived of as population processes, that characterize differences between major population groups, rather than individual differences within populations. Following that point of view, greater insights might then be gained by studying maturational aging as variations in population parameters, rather than as meaningful differences at the level of the individual.

### *Implications for Sequential Data Collections*

Broadening the cohort construct to allow for cohort groupings, membership in which is not necessarily a function of common chronological age boundaries, and redefining period effects as event time has the immediate consequence of breaking the dependency between these effects and calendar time. In the extreme instance, then, where either cohort and/or period is orthogonal to chronological age, the indeterminacies contained within the general developmental model as originally stated are no longer inevitable. In other instances, the indeterminacy is partially broken. Given our reconceptualization of cohort and period it is now possible to imagine, at least for limited life stages, research designs that permit the independent specification of age, cohort, and period effects.

When the dimensions of the general developmental model were originally constrained by calendar time, it soon became apparent that the cohort-sequential method (i.e., analysis of age × cohort data matrices) was the approach of choice (cf. Baltes, 1968; Buss, 1973; Schaie & Baltes, 1975). Freeing our constructs from the tyranny of the calendar, however, raises serious questions whether this conclusion can remain valid. If pure aging is viewed as a species-specific population process, then the differentiation of intraindividual change and interindividual differences may become primarily a nature–nurture issue. That is, the cohort-sequential method would have useful applications primarily in the study of developmental behavior genetics (Schaie, 1975).

For those of us interested in individual differences, however, the primary concern now turns to the differentiation of interindividual differences in intraindividual change across time from interindividual differences in level at a particular point in time. This differentiation can best be accomplished by studying the timewise more economical research paradigm employing cohort × time response matrices, applying what has been called the cross-sequential method (Schaie, 1965, 1977). By defining cohort as a selection variable and period as an event density index, calendar age has been effectively removed as a confound for cohort or period. For dependent variables with suitable age distributions, it would therefore be possible to specify factorial models that completely cross chronological age, event time, and/or cohort selection variables. Alternatively, the option exists to treat calendar age as part of the dependent variable and/or to use nonchronological indices of age as covariates in our analysis, independent of calendar time.[2]

For the developmental social psychologist, the time-sequential method becomes of interest, since it permits differentiation of age/cohort status from period effects. Once period effects are redefined as event density indices, the confound with cohort is removed. Indeed, age now has the primary function of classifying subjects by the *duration* from birth to the

[2] Calendar time, of course, is not dependent upon anything under the control of social or behavioral scientists. Nevertheless, it seems to be a quite legitimate exercise to predict the time required to elapse as a developmental event or sequence unfolds. It is only in this sense that calendar time would be treated as a dependent variable in the analyses proposed in this article.



points in calendar time where the event density is being measured and thus simply becomes another possible (cohort) selection variable. This use of chronological age is attaining increasing importance in the sociological literature on age stratification (cf. Foner & Schwab, 1983; Riley, 1985). The principal conceptual distinction between the cross-sequential and time-sequential method under the new definitions, then, lies in the fact that period effects will be interindividual differences in intraindividual change in the former, but time-ordered, interindividual differences in the latter; repeated measurements are thus required in the cross-sequential design, while successive independent samples would characterize the time-sequential data matrix.

## EXPANDED FORMULATIONS OF THE GENERAL DEVELOPMENTAL MODEL

### *Brief Summary of the Original Model*

This section first reviews some of the formal aspects of the original model and then shows the consequences of redefining the major parameters of the model. In the original formulation (Schaie, 1965), it was specified that any developmental change could potentially be decomposed as being influenced by one or more of three independent sources. The general equation offered was of the form

$$R = f(A,C,T) \qquad (1)$$

where the observed change in response ($R$) is a function of age (maturational) change ($A$), differences between cohorts in experiences that occurred prior to the first time-of-measurement ($C$), and environmental impact (period effects) that occurred between two measurement points ($T$). Estimation of Eq. (1) for empirical data, assuming equal interval boundaries expressed in calendar time, would then be of the form

$$X_{ijk} = a_i + c_j + t + ac_{ij} + at_{ik} + ct_{jk} + act_{ijk} + e_{ijk}. \qquad (2)$$

Examining the ways in which developmentally oriented data are usually collected, it became clear that the traditional cross-sectional and longitudinal approaches (together with a third alternative, that was called "time-lag") were simply special cases of the model in which one of the terms was set to zero, while the other two were confounded. In *cross-sectional* studies, data are collected at a single point in time for two or more samples differing in chronological age. Successive cross-sectional samples, by definition, must be drawn from different birth cohorts. A single-point study does not reflect any period effects, but individual differences on the dependent variable must be composed of some combination of variances associated with differences in age and cohort. Traditional single-cohort *longitudinal* studies collect data on a group of individuals, typically homogeneous in age, and assess that group at successive multiple points in time. The longitudinal sample does not reflect any cohort differences, but it confounds the effects of age changes in the dependent variable with period effects occurring over the calendar time during which change is monitored. In the third alternative, a *time-lag* study would sample individuals of the same chronological age at different calendar times. Such samples, of course, would also have to come from different birth cohorts. In this strategy, there would be a confound of cohort and period effects.

Realizing the differential composition of cross-sectional age differences and longitudinal age changes, it became clear that such age effects could be equivalent only under the excessively strong assumption that both cohort and period effects were zero over the time/cohort frame from which data to be compared had been sampled. To estimate pure "age" effects it would therefore be necessary to decompose the sources of developmental variance. It was proposed therefore that it would be necessary to collect *sequential* data, in essence advocating replication of either cross-sectional and/or longitudinal studies (also cf. Schaie & Baltes, 1975), in order have a sufficient set of equations that would permit decomposing individual differences in terms of the three sources of developmental change specified above. It soon became apparent, however, that unambiguous decomposition of the three components was possible only by imposing the side condition that

$$\text{either } a_i = 0, \text{ or } c_j = 0, \text{ or } t_k = 0, \tag{3}$$

and that the triple interaction as well as the simple interactions involving the main effect set to 0, were also set to 0.

Given any one of these side conditions, it can be shown that the classical ANOVA approach can be used to partition the variance associated with any set of observed measures of change into the remaining two components and their interaction. Three strategies were proposed that serve to partition the variance associated with any combination of two of the three postulated components.

The first strategy was called *cohort-sequential* (*CS*) and requires that at least two cohorts be assessed at at least two age levels (requiring a minimum of three times of measurement). Decomposition can then occur in the form

$$Xcs_{ij} = a_i + c_j + ac_{ij} + e_{ij}. \tag{4}$$

Data for the age × cohort matrix can be obtained by repeatedly measuring the same cohorts, in which case the cohort component represents individual differences while the age component and the interaction represent intraindividual change. Alternatively the data matrix may be formed by the repeated assessment of successive independent random samples from the same population cohorts. In the latter case, the age component and interaction represent shifts in age-indexed population parameters.



The second strategy was termed *time-sequential* (*TS*) and requires that at least two age levels be assessed at a minimum of two times of measurement. To fill this data matrix, one would ordinarily require a minimum of four samples extending across three cohort levels. Decomposition of this matrix is of the form

$$Xts_{ik} = a_i + t_k + at_{ik} + e_{ik}. \tag{5}$$

All components of this age × period model involve population estimates, and no estimates of intraindividual change are provided.

The third strategy, called *cross-sequential* (*XS*), requires a minimum of two cohorts assessed at two times of measurement (in this instance involving at least three age levels). This matrix can be decomposed as follows,

$$Xxs_{jk} = c_j + t_k + ct_{jk} + e_{jk}. \tag{6}$$

As for the cohort-sequential strategy, it is possible to assess samples repeatedly to yield individual difference estimates between cohorts, and a period component and cohort × period interaction that estimate intraindividual change. Alternatively, independent random samples from successive cohorts would yield estimates that reflect population differences between cohorts and across time for all parameters.

As suggested in our earlier discussion, violation of any of the side conditions stated above would cast doubt upon the interpretation of estimates for any of the components, and violation of the equal-interval assumption would further compromise interpretations regarding the relative importance of any of the components. In the past, then, whenever there was reason to suspect the plausibility of the side conditions, only intuitive attempts at planned design misspecifications remained (cf. Schaie & Hertzog, 1983; Schaie & Labouvie-Vief, 1974; Schaie & Parham, 1974, 1976).

### *Expanded Formulation of the Model*

One of the major problems that prevented specification of a strategy that could simultaneously estimate the entire three-component model resulted from the trapezoidal data matrix decreed by the dependence of all components of the model upon calendar time (cf. Schaie, 1965, pp. 92–93). Once calendar time is divorced from one or more of the model's components, then simultaneous decomposition becomes possible, whether or not the specified components are orthogonal with respect to each other. The components of Eq. (1) now attain at the same time a conceptually more general, but operationally more precise, meaning. That is, age ($A$) now becomes an estimate of the individual's progression through life, measured in terms of some functional parameters that may modestly correlate with, but are not simply surrogates of, chronological age. Cohort ($C$) represents attainment of group membership on any selection variable at a common temporal point. The temporal points may be correlated with the calendar time indexing the individual's birth, but such correlation might be zero or quite modest for a particular cohort definition. Finally, time-of-measurement or period ($T$) is taken to represent event time, which for convenience may be scaled in conventional calendar time units, but whose intervals since they represent experiential elapsed time will generally be only modestly correlated with the mere passing of calendar time. Within this more general formulation of the general developmental model, Eq. (1) in its original form represents the most restrictive condition (that where only a subset of two components can be estimated under restrictive assumptions). Equation (1) should therefore be rewritten more explicitly in the form

$$R = f(A_C, C_B, T_C), \qquad (7)$$

where $A_C$ equals chronological age, $C_B$ equals birth cohort, and $T_C$ represent calendar time, the original restrictive assumptions.

### *Less Restrictive Models*

Depending upon whether calendar constraints are abandoned for any or all of the three components of developmental change, it is now possible to reformulate Eq. (7) by substituting the more general (calendar free) form for one or more of the components. Using definitions provided above, seven other less restrictive formulations can then be given for the original model. Each of these models will permit the direct estimation of one or more of the reformulated components, under the assumption of orthogonality. If the latter assumption is deemed unreasonable or unduly restrictive it is possible also to suggest empirical data sets that would allow estimating all three components of developmental change using Eq. (2) without the need to impose any of the side conditions essential for the original model.

*1. Cohort defined as a selection variable.* When cohorts selected by criteria other than year of birth are crossed with chronological age and calendar time periods, the model would take the form

$$R = f(A_C, C, T_C). \qquad (8)$$

Under this model assumption it would be permissible to conduct a cross-sectional study comparing cohorts with different temporal entry points at one point in time. The obtained cohort differences would now no longer be hopelessly confounded with chronological age, even though they might be correlated with chronological age to a greater or lesser extent. It is now also possible to fill all cells for any reasonable rectangular age/cohort/period combination. As indicated above, the age component, however, now becomes another classification variable (calendar time from birth); it represents individual differences in such classification, not intraindividual change. The ANOVA paradigm for this model would be analogous to the time-sequential design (cf. Schaie, 1977, p. 47, Table 5) with cohort as a third (between-groups) factorial level. An example of such a design might be the study of paternal involvement in child rearing at different life stages (e.g., Rossi, 1980). Cohort would here be defined as paternal life status at a specified age for the reference child (e.g., father still in college, father unemployed, father in probationary job, father in established career).

*2. Period defined as event density.* Noncalendar time-of-measurement periods can likewise be crossed with birth cohort and chronological age. The model then takes the form

$$R = f(A_C, C_B, T). \qquad (9)$$

Given this model, it would be permissible to conduct a single-cohort longitudinal study, to infer unambiguously the amount of change on a dependent variable as a function of period effect occurring between specified event times, unconfounded by chronological age. Note that given this model it is quite feasible for certain events to occur in reverse order for different cohorts, and such events could certainly be experienced at different chronological ages (cf. Hogan, 1978). Content-specific event density classification could, therefore, be crossed within an age × cohort data matrix. The age component would involve maturational intraindividual change, the birth cohort would index experiential differences due to the time ordering of successive generations, and the period effect would indicate interindividual differences in the experience of a particular class of events. The ANOVA paradigm would be analogous to the cohort-sequential design with repeated measurements (cf. Schaie, 1977, p. 44, Table 2) with an additional between-groups factor for the levels of the period effect. An example of this design might be found in the study of life stress (e.g., Elliott & Eisdorfer, 1982), where period would be defined in terms of the occurrence of major stressful events (or stress event density levels), and age and birth cohort would be defined as usual.

*3. Age defined as functional or subjectively perceived age.* Any estimate of functional level that relates to chronological age in a nonmonotonic fashion (e.g., Heron & Chown, 1967; Nuttall, 1972; Schaie & Parr,

1981) could be combined with the conventional cohort × period response matrix to yield a model of the form

$$R = f(A, C_B, T_C). \tag{10}$$

Here age once again serves as a classification variable, except that its base is nonchronological in nature. Under these circumstances it would be permissible to conduct cross-sectional studies that would vary functional or subjectively perceived age levels across groups under study. Age differences thus defined would be unconfounded with birth cohort. The full ANOVA paradigm would be analogous to the cross-sequential design with repeated measurements (cf. Schaie, 1977, p. 49, Table 7) with an additional between-group factor for the levels of functional or subjectively perceived age. This is a particularly interesting model as it would lend itself well to studies of objectively definable performance variables and their subjective perceptions that might underlie various policy decisions with respect to such issues as mandatory retirement, future structuring of the pension system, etc. (also see Stagner, 1985). That is, we could now classify individuals in terms of functional age levels, and then decompose developmental variance into those sources attributable to individual differences in such levels, individual difference in intraindividual change over specified time periods, as well as differences between successive birth cohorts.

The remaining four models present further extensions in those instances where it becomes of interest to free two or all of the model components from the conventional calendar restraint.

4. *Non-calendar definitions of both cohort and period.* Crossing chronological age with noncalendar definitions of cohort and period would result in the model

$$R = f(A_C, C, T). \tag{11}$$

If chronological age is represented as maturational level, and the age estimate for the dependent variable is to reflect intraindividual change, then this design would be analogous to the cohort-sequential paradigm with repeated measurement (cf. Schaie, 1977, p. 44, Table 2) with an additional between-group factor for period defined as event time. This model would be of interest, perhaps, in anthropometric studies tracking the development of physical characteristics, while controlling for the effects of specific external events, and temporal cohort selection variables. For example, we may wish to investigate growth during adolescence, over temporal periods having greater or lesser amounts of environmental stressors, in cohort groupings defined by common points of entry of mothers into nutrition education or other health management efforts for which our subjects are the target population.



5. *Noncalendar definitions of age and period.* This model crosses birth cohort with functional age and event time, and is of the form

$$R = f(A, C_B, T). \tag{12}$$

This model would be of interest in the assessment of intraindividual change in functional age or subjectively perceived age definitions when crossed with membership in specific birth cohorts, observed at specific event times. The cohort-sequential paradigm with repeated measurement is again appropriate, except that the additional between-group factor would now be event time. Here it would be possible to identify, for example, behavior consequences of differential life courses within generations, contrasted to differences between birth cohorts (e.g., Bengtson, Furlong, & Laufer, 1974; Campbell & Bengtson, 1984).

6. *Noncalendar definitions of age and cohort.* When calendar time (period) is crossed with functional age and selection cohort, the resulting model takes the form

$$R = f(A, C, T_C). \tag{13}$$

This model may fit some behavioral phenomena as well as epidemiological population characteristics that might conveniently be monitored over a calendar time frame, but where both functional age and cohort definitions would be preferred. For example, time indexed economic change, across different selection cohorts, might be assessed for samples differing in health status, defined as functional age (e.g., Brenner & Mooney, 1982). The appropriate ANOVA model would be analogous to the cross-sequential repeated measurement paradigm with functional age as an additional between-group factor.

7. *Noncalendar definitions of all three components.* Finally, a model can be specified that breaks completely from any required association with calendar time and would be of the form

$$R = f(A, C, T). \tag{14}$$

The data matrix representing this model would consist of samples structured by functional age, cohort selection variable, and event time, where age is also conceptualized as a selection variable. Since all three components are classification variables they would represent a straightforward three-factor between-group ANOVA paradigm. This model would seem to provide the proper intuitive base for age–period–cohort analyses of the type proposed by Mason et al. (1973). It may also be appropriate in those instances where it is possible to define subjective definitions of age that have behavioral consequences dependent on temporal group membership (cohort) and event time (e.g., Miller, Gurin, & Gurin, 1980).

An alternate mixed form of this model would fit experimental paradigms where functional age is the between-group classification variable, where cohort represents between-group treatments, and where time represents within-group treatments. This paradigm would be useful in experimental studies of expertise that begin by equating the performance levels of individuals at different ages (e.g., the Salthouse & Saults (in press) study of expert typists). Such studies commonly confound temporal point of attainment of expertise, the event history that maintains or enhances the expertise, with the observed functional level of the expert. When performance levels have been set orthogonal to chronological age, different performance levels would actually represent and could be expressed as levels of *functional* age. Cohort groupings in this example would represent common temporal points of entry into the expert class. The within-sample variance, finally, would represent the event density; i.e., the occurrence of events that are thought to be essential for the development of expert performance.

### *Alternative Statistical Approaches to Model Estimation*

Once the indeterminacy of the relations between age, time, and cohort is broken, it becomes reasonable again to utilize ANOVA approaches to the analysis of directly observed variables, particularly in those instances where chronological age is to be used as a selection variable or where the analysis involves noncontinuous categorical cohort levels (see Schaie, 1977; Schaie & Hertzog, 1982).[3] Employing the ANOVA approach has also been convenient in relating the reformulated models to the earlier work. Nevertheless, the point should be made that there is no disagreement with those who would argue that the study of latent constructs, or the decomposition of whole variable systems into their sources of developmental variance, should employ the more elegant methods of linear structural analysis (cf. Bentler, 1980; Hertzog & Schaie, in press; Horn & McArdle, 1980; Joreskog, 1979; Schaie & Hertzog, 1982, 1985).

## SUMMARY AND CONCLUSIONS

The goal of the original specification of a general developmental design model had been to provide methodologies for a more valid description of developmental phenomena occurring over time. Applying these methods to empirical data led to the realization that chronological age as such had limited explanatory power as an indicator of individual status on the behavioral phenomena of interest. Attention therefore shifted to the contextual dimensions of cohort and period (time-of-measurement), that were originally seen as unwanted confounds of age changes, to be controlled as threats to the internal validity of our studies. It soon became evident, however, that these constructs, rather than being inconvenient confounds, are of direct interest to the developmental scientist.

Much effort has been given to the task of devising methods for separating cohort and period from chronological age, but relatively few attempts have been made to assign specific meaning to these concepts. In this article, the argument has been made that cohort and period must be freed from their dependence upon calendar time. Cohort has been redefined as a selection variable and some organizing principles have been suggested as to the various ways in which cohorts can be composed. Similarly, period was redefined as event time, various attributes of events were examined, and an approach toward the scaling of historical time was suggested that might lead to the development of event density indices. It was then shown how the indeterminacies contained in the general developmental model can be resolved, if one or more of the component constructs can be redefined in the manner suggested here.

With respect to the age variable, moreover, it was suggested that it may be time to begin treating calendar age as a measure of time elapsed in developmental progression, that in a regression sense should be operationally assigned to the dependent variable side of the equation. When used as an independent variable, age might alternatively be reconceptualized as a noncalendar functional age. Pure aging effects were conceptualized, moreover, as a population process rather than as an individual differences variable. As a consequence, it was suggested that the sequential data matrix of choice might shift from the cohort-sequential to the cross-sequential design. The latter would permit differentiating effects due to individual differences in intraindividual change, that should be of primary interest to developmentalists. Other consequences for sequential analyses were also considered, and some formal definitions were provided for an expansion of the general model.

Much more needs to be said about the specific ways in which the proposed reconceptualizations will affect interpretation and design of the conventional developmental data collections. There are as yet few data sets that would readily lend themselves to secondary analyses using the proposed paradigm, and the examples given in this paper reflect largely possible rather than actually conducted analyses. Indeed, much of what is presented here requires much further thought, explication, and operationalization. For that to happen, however, it seemed necessary first of all to attempt to break the methodological impasse, and to show how the apparent indeterminacy of the age–period–cohort model might possibly be circumvented. As work proceeds along these lines, it may finally be possible to move beyond creating chronicles of behavior change as we move through time, to the discovery and disaggregation of the specific influences that determine such changes.

[3] Recent refinements for the analysis of sequential data matrices are described in Schaie and Hertzog (1982, 1983, 1985).

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