The Interface of Behavior and Biology: Contributions of Longitudinal Studies

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Abstract

This paper considers the contributions of longitudinal studies of behavioral development in integrating the influences of biological and environmental influences. We provide a conceptual framework for understanding the sample case of adult cognitive development and focus on the biological, social and psychological sources of individual differences in development, the impact of generational differences and the possible role of behavior in predicting mortality.

THE INTERFACE OF BEHAVIOR AND BIOLOGY: CONTRIBUTIONS OF LONGITUDINAL STUDIES

Introduction

Behavioral scientists have long accepted the dictum that the relation between behavior and biology is likely to have reciprocal character. That is, behavior necessarily occurs within the constraints of our biological infra-structure which must therefore be considered as providing at least someantecedents for a given behavior. However, just as individuals are shaped by their social context and in turn shape that context, there are behaviors which may modify the sequence of biologically based events. For example, cognitive abilities and acquired knowledge may affect the onset and course of chronic diseases through the display of positive health behaviors including the adoption of healthy life styles and adherence to the regimens implicit in successful intervention programs.

Given the reciprocal relationship between behavior and biology it becomes important to sort out directionality and to determine whether biology or behavior should be seen as antecedent whenever significant relationships are observed. It is obvious that such sorting out can not readily be accomplished by concurrently observed data. Hence, one must either make strong assumptions about directionality, or provide a direct test via longitudinal studies that permit structural modeling of alternative outcomes.

Having done virtually all my work on developmental issues over the successive stages of adulthood, I will therefore not deal with the first two decades of life. Instead I will discuss relevant research that has been conducted as part of the Seattle Longitudinal Study (SLS) which will highlight some of the reasons why longitudinal data are essential for understanding the interface of behavior and biology. I will also try to make the case that this relationship can not be fully explored unless we include the social environment as well. My sample case will be the adult development of cognition.

A Framework For Understanding Adult Cognitive Development

To understand development of a behavioral process from young adulthood to old age it is necessary to specify what we know about behavioral development within the changes in individuals' physiological infra-structure as well as the context of changing environmental influences.

Figure 1 displays a schematic that specifies my particular view of how these influences might operate over the adult life course in the special case of cognition (Schaie, 2000). The schematic contains two endpoints; one important for clinical and/or social policy issues, the other of greater concern to basic science. The first endpoint is concerned with the lifelong influences that effect the level of late life cognitive functioning so essential for maintaining independence and a life characterized by high quality. The second endpoint represents the status of the cortex at life's end and is descriptive of the biological infra-structure relevant to the maintenance of cognitive functioning

as it is determined at post mortem. In this conceptual path model, as is conventional, rectangles are used to identify those individual indicators that are observed directly while ovals are used to indicate the latent constructs which would be inferred from measurement models for sets of observed variables.

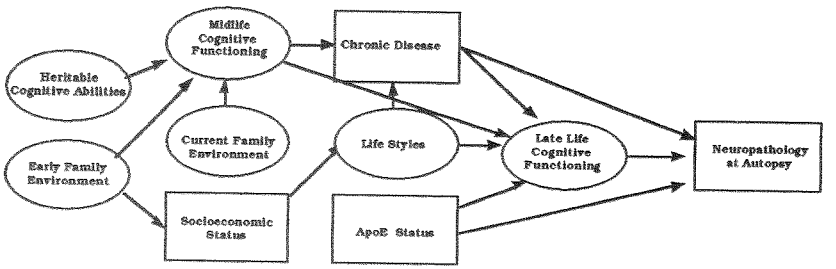

Figure 1. A framework for understanding adult cognitive development

You may wish to argue immediately that the arrows in this figure that represent the interplay of various causal influences may be overly simplistic. In particular, you might wish to propose that several of these relationships could well be reciprocal in nature. But please bear with me that I have tried to keep the model as simple as possible, since it is intended primarily for its heuristic value. More complex models would be required if the model were to be fitted to specific sets of data.. However, I would like to assure you that all of the causal paths specified in the model can be supported by the results of empirical

investigations in my own laboratory or those of other cognitive developmentalists.

Let me provide a few more details about the attributes of the heuristic model. The initial origin of adult cognitive functioning can be attributed to both heritable (genetic) influences as well as to early environmental influences typically experienced within the home of the biological parents. Some of the behavior genetic literature suggests that early environmental variance is largely non-shared (e.g., Plomin & Daniels, 1987). But we have found retrospective evidence that there may indeed be some early shared environmental influences upon later cognitive performance (Schaie & Zuo, 2001). Both generic and early environmental factors are thought to influence midlife cognitive functioning. The early environmental influences will, of course, also exert influences on midlife social status (Nguyen, 2000). By contrast, virtually no correlations have been found between retrospective accounts of family environment in the family of origin, and that in the current family (Schaie & Willis, 1995). However, the current family environment does seem to influence midlife cognitive performance. Genetic factors are also likely to be implicated in the rate of cognitive decline in adulthood. Thus far the best-studied gene in this context is the Apo-E gene, one of whose alleles is thought to be a risk factor for Alzheimer's disease. Apo-E status is therefore added as a factor; the expression of the gene is probably not at issue prior to midlife (Schaie, 2004)..

Given the above considerations, the causal influences can now be specified that determine level of cognitive function in late life as well as

cortical status at autopsy. The direct influences to be implicated in addition to genes whose expression is turned on in late life, most likely originate in midlife. They include level of cognitive functioning in midlife, midlife life styles, and the incidence and severity of chronic disease. But there are indirect influences attributable to the effects of midlife cognitive function and life styles upon chronic disease, as well as shared family influences on midlife cognition and of social status upon midlife life styles (cf. Willis & Reid, 1999)..

Some of these paths represent concurrent observations which would allow alternative (respectively reciprocal causal paths), but most of the paths specified by the model represent antecedent-consequent relationships which require longitudinal data for their estimation and understanding. Hence, I next turn to a brief account of what has been learned from longitudinal studies about the multiple influences of biological and social influence upon adult cognitive development.

Longitudinal Studies of Adult Development

The initial longitudinal studies that have informed our understanding of adult development were of two types. First, there were studies that began with a focus on early childhood and child rearing practices, but whose participants were followed into adulthood. A prime example of such a study is the followup of the Berkeley Growth and Guidance studies (Bayley & Oden, 1958; Eichorn, Clausen, Haan, Honzik, & Mussen, 1981). A second group of studies traced participants who had been assessed as young adults as part of their college

experience and reassessed in midlife or later. An example of such studies is Owens (1953, 1966) followup of persons in their 50s who had first been assessed as ROTC members during World War I.

Life-span oriented studies

The early work on adult development was pretty much oriented within the context of a life-span development framework (cf. Baltes, 1987, 1997), but the burgeoning field of geropsychology soon divided into at least two rather different orientations. Some investigators remained committed to the notion that an understanding of the aging process required the careful charting of human development at least across the entire adult life span, if not beginning our inquiries in childhood. This orientation, which I share, holds that what is of primary interest is the understanding of the mechanisms that contribute to the behavioral differences between youth and old age within a process that extends across the life span. Most of the studies of children followed into adulthood illustrate this type of approach.

Studies originating in late life

A second type of study considers the characteristics of the elderly to be of primary interest, and investigate the aging process only from that period of life when a categorical transformation, such as leaving the world of work, or family dissolution due to death of a spouse has occurred. Representative longitudinal studies of this type therefore begin at an advanced age. Several of these studies began during the 1960s and 1970s.

Perhaps the most prominent of late life studies has been the Duke Longitudinal Study (Palmore, Busse, Maddox, Nowlin, & Siegler, 1985). But many others can be found in the literature conducted in a variety of industrial societies (e.g., Canada: Hultsch, Hertzog, Dixon, & Small, 1998; Germany: Schmitz-Scherzer & Thomae, 1983; Rott, 1993; Sweden: Svensson, Dehlin, Hagberg, & Samuelsson, 1993; United Kingdom: Rabbit, 1993). Other more recent studies have focused on following those in very late life (e.g. Baltes & Mayer, 1999; Poon, Sweeney, Clayton, & Merriam, 1992).

Patterns of cognitive decline

These studies generally find less decrement than would be suggested by cross-sectional data, only small average decline in the sixties, with increasingly steep decrement for each successive age decade. There is also a strong suggestion that decline accelerates as a precursor of eventual death (Berg, 1996; Bosworth, Schaie, Willis, & Siegler, 1999). But most importantly, all of the studies call attention to vast individual differences in rate of change occurring for individuals of all levels of psychological functioning and socio-economic status. Although the frequency of individuals showing detectable decline increases at a near logarithmic rate once the 60s are passed, there are still rare individuals to be found even in the mid-80s who function exceedingly well.

What many of these studies also suggest is that there can be highly individualized pattern of developmental trajectories (cf. Magnusson, 1998). For example, in the case of mental abilities, most individuals by the time they

reach the 60s will have experienced a significant drop in one of their abilities, but that ability will be specific to the individual (see Figure 2; Schaie, 1989). Indeed, it is the longitudinal study of adult development that permits inquiry into possible mechanisms and/or causes of these vast individual differences in developmental progressions through adulthood (cf. Schaie and Hofer, 2001).

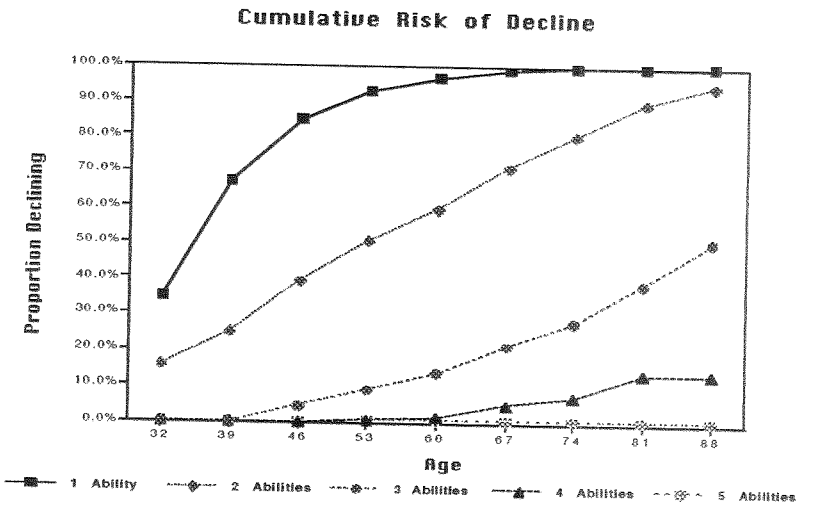

Figure 2. Cumulative risk of decline of multiple abilities

Sources of Individual Differences

Individual differences in trajectories and patterns of decline invite investigations of influences that can be identified as potential causes of unfavorable or successful aging. While some of these influences can be represented by psychological constructs, others must clearly be sought in the physiological infrastructure underlying effective behavior, as well as the socio-demographic factors that will either benefit or constrain individual development. The developmental impact of all of these influences can, of course, only be assessed when relevant longitudinal data are available.

Not all individuals decline in lock-step. Although linear or quadratic forms of decline may be detectable for large groups, individual decline appears to occur far more frequently in a stair-step fashion. Individuals will have unfavorable experiences, to which they respond with a modest decline in cognitive functioning, and then tend to stabilize for some time, perhaps repeating this pattern several times prior to their demise.

Genetic Influences

Certainly, genetic endowment will account for a substantial portion of individual differences. For example, evidence of heritability of adult intelligence has been provided from both twin studies (e.g., Finkel, Pedersen, McGue, & McClearn, 1995) and family studies (e.g. Schaie, Plomin, Willis, Gruber-Baldini, & Dutta, 1992). Similarly, genetic variance has been identified for a variety of personality traits as well as their stability in adulthood (e.g., Pedersen & Reynolds, 1998). Nevertheless, in most populations sampled,

heritability explains on average at most 25% of cognitive abilities and less in the realm of personality. Hence, there are many other important sources of individual differences in psychological aging that have been implicated.

Chronic Disease

The onset of intellectual decline seems to be markedly affected by the presence or absence of several chronic diseases. Most reliably identified as such influences thus far are cardiovascular disease, diabetes, neoplasms, and arthritis. All of these diseases are risk factors for the occurrence of early cognitive decline, as is a low level of overall health. Persons functioning at high cognitive levels are also more likely to seek earlier and more competent medical intervention in the disabling conditions of late life, and they are more likely to comply more effectively with preventive and ameliorative regimens that tend to stabilize their physiological infrastructure. They are also less likely to engage in high-risk life styles and to respond more readily to professional advice that maximizes their chances for survival and reduction of morbidity (e.g. Bosworth & Schaie, 1999; Schaie, Leventhal, & Willis, 2002).

Environmental circumstances

Candidates of circumstances that might account for individual differences in cognitive aging, for example, have been all those aspects of the environment that are likely to enhance intellectual stimulation (cf. Schaie & O'Hanlon, 1990). There is considerable evidence to suggest that the onset of intellectual decline is postponed for individuals who live in favorable environmental circumstances, as would be the case for those persons

characterized by a high socioeconomic status. These circumstances include above-average education, histories of occupational pursuits that involve high complexity and low routine, and the maintenance of intact families. Likewise, risk of cognitive decline is lower for persons with substantial involvement in activities typically available in complex and intellectually stimulating environments. Such activities include extensive reading, travel, attendance at cultural events, pursuit of continuing education activities, and participation in clubs and professional associations (Arbuckle, Gold, Andres, & Schwartzman, 1992; Gribbin, Schaie, & Parham, 1980)..

Intact families, our most important individual support system, also reduce risk of cognitive decline. In addition, it has been found that cognitive decline is less severe for those married to a spouse with high cognitive status, with the lower-functioning spouse at the beginning of a marriage tending to increase his or her level vis-a-vis the higher-functioning spouse (Gruber-Baldini, Schaie, & Willis, 1995).

Psychological characteristics

Cognitive styles. Associated also with differential intellectual aging have been individual differences in the cognitive style of rigidity-flexibility. It can now be concluded that an individual's self-report of a flexible personality style at *midlife*, as well as flexible performance on objective measures of motor-cognitive perseveration tasks, is predictive of a reduction in the risk of cognitive decline. It seems that the availability of a more flexible response style is useful when it one must cope with the vicissitudes of advanced age. On the

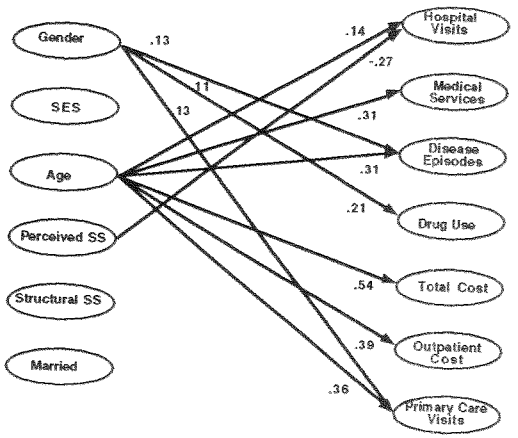

Figure 3. Perceptions of social support and health outcomes

other hand persons with rigid personality are more likely to follow rigorous treatment regimen.

Perceptual and response speed. Aging effects on many cognitive abilities tend to be confounded with the perceptual and response speed required to process the tasks used to measure these abilities. Thus, individuals who remain at high levels of perceptual speed are also at an advantage with respect to the maintenance of such other abilities.

Perception of social support. I should also mention that it is not actual social support but the perception of social support that is substantially related to a whole spectrum of health-related variables, including the utilization and cost of health services (cf. Figure 3; Bosworth & Schaie, 1997)..

The Impact of Generational Differences

One of the major contributions made by developmentalists interested in adulthood has been the attention given to generational (or cohort) differences in psychological characteristics, including shifts in the rate of developmental change across successive cohorts. What is at issue here is that we can not rest certain that once we have explicated developmental mechanism and life course trajectories that these will stay put. As Riley (Riley, Foner, & Riley, 1999) vividly portrays, changing societies change the life course of individuals, who in turn during their life course modify the formative nature of society. The cohort issue has long been of central concern in sociology and demography. In developmental psychology as well as in biology, cohort was first seen as a confound that created the unwelcome discrepancies between cross-sectional and longitudinal findings. Hence, initial concerns where with attempts to control for what were perceived to be "experimental artifacts."

Cohort variance in studies of infancy and childhood may indeed be no more than a minor disturbance unlikely to overshadow or hide universal developmental laws. By contrast, cohort variance often assumes a substantively meaningful role in the study of adult development. Individual

differences in adulthood, prior to advanced old age, are largely moderated by environmental context. It is therefore important understand how successive cohorts differ from one another (Schaie, 1996; Willis, 1989). Examples of major contexts that differ dramatically for successive generations can be found in the increased level of educational attainment, the adoption of healthy life styles with respect to exercise and diet, and major advances in health care that contribute to the extension of life and functionality. The increase in societal support during early old age has resulted in compensatory behaviors that optimize selective psychological functions (cf. Baltes & Carstensen, 1996). Figure 4 shows an example of cohort trends in cognitive abilities, that illustrate both positive and negative trends (cf. Schaie, 2004).

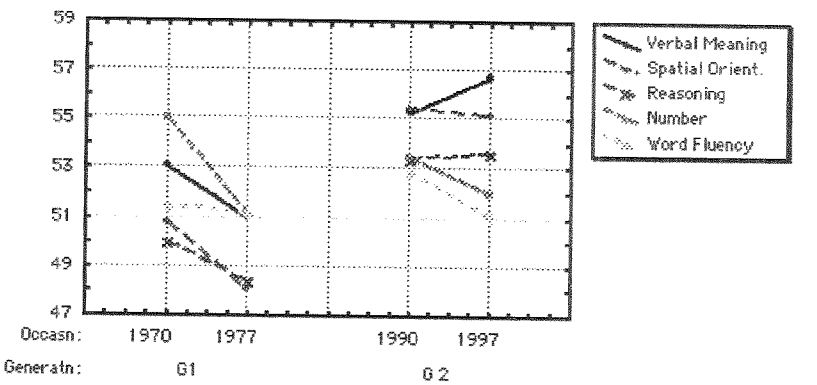

Figure 4. Cognitive changes over seven years in young-old age for parent-offspring dyads

What these data show is that most dimensions of cognitive competence across two biologically related generations of study participants over the age range from 60 to 67. This, of course, is the age span during which most individuals could typically be expected to retire, and the data support the assumption that performance over this age range has indeed risen. There is also support for the second assumption of changes in rates of aging (except for the variable of number skill for which rate of aging has remained fairly constant and overall level is actually decreasing. (see Figure 4).

Cognitive Predictors of Mortality

I finally turn to the other side of the coin in the relation between behavior and biology. That is, decremental changes in complex behaviors such as cognition may also be seen as indicators of imminent biological systems failure. Again longitudinal data are needed in order to be able to show that such indicators may be observed prior to the occurrence of clinical signs of impending mortality. As indicated in Table 1, excess risk of mortality can be found for level of function at last cognitive assessment, and as a function of the magnitude of cognitive decline over seven years (cf. Bosworth, Schaie, & Willis, 1999).

Table 1. Odds Ratios for Mortality of Lowest and Highest Quartile

Cognitive variable	Performance at Base Line	Decline over 7 years
Verbal Meaning	1.67	1.74
Inductive Reasoning		1.45
Spatial Orientation	1.38	2.09
Number Skill	1.42	
Immediate Recall	1.87	
Delayed Recall	1.97	
Identical Pictures	2.32	
Psychomotor Speed	1.51	2.10

Future Implications

The study of adult psychological development is increasingly informed by relevant neighboring disciplines that investigate the genetic basis, physiological infra-structure and societal context of the developing individual. Hence, it is likely that the study of the life course of single psychological variables, that was so common in the first two thirds of the past century, will be largely displaced by multivariate multi-disciplinary efforts. Indeed, most of the more recent longitudinal studies of adults already display these characteristics (e.g. Baltes & Mayer, 1999). Cross-sectional investigations will continue to have a role as exploratory pilot studies or as the first stage of a prospective longitudinal study. Given the willingness of public agencies to invest in more comprehensive investigations we are likely to see more programmatic long-range investigation that may frequently include experimental paradigm and in particular interventions designed to modify rate of development Indeed, there

will also be a shift from focus on group means to the definition of typologies of individual trajectories. All of these effort will have to be framed within the changing physiological constraints across age as well as the social-cultural context experienced by sub-sets of the population. Hence, I would argue that integration of psychological science with its neighboring disciplines is not only desirable but inevitable

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