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LIFESPAN PSYCHOLOGY: Theory and Application to Intellectual Functioning

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ABSTRACT

The focus of this review is on theory and research of lifespan (lifespan developmental) psychology. The theoretical analysis integrates evolutionary and ontogenetic perspectives on cultural and human development across several levels of analysis. Specific predictions are advanced dealing with the general architecture of lifespan ontogeny, including its directionality and age-differential allocation of developmental resources into the three major goals of developmental adaptation: growth, maintenance, and regulation of loss. Consistent with this general lifespan architecture, a meta-theory of development is outlined that is based on the orchestrated and adaptive interplay between three processes of behavioral regulation: selection, optimization, and compensation. Finally, these propositions and predictions about the general nature of lifespan development are examined and supported by empirical evidence on the development of cognition and intelligence across the life span.

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INTRODUCTION

Lifespan developmental psychology or lifespan psychology (LP) deals with the study of individual development (ontogenesis) from conception into old age (PB Baltes et al 1980, Dixon & Lerner 1988, Neugarten 1996, Thomae 1979). A core assumption of LP is that development is not completed at adulthood but that it extends across the entire life course and that from conception onward lifelong adaptive processes of acquisition, maintenance, transformation, and attrition in psychological structures and functions are involved. The simultaneous concern for acquisition, maintenance, transformation, and attrition exemplifies the view of lifespan psychologists that the overall ontogenesis of mind and behavior is dynamic, multidimensional, multifunctional, and nonlinear (PB Baltes 1997).

Lifespan research and theory is intended to generate knowledge about three components of individual development: (*a*) interindividual commonalities (regularities) in development; (*b*) interindividual differences in development; and (*c*) intraindividual plasticity (malleability) in development. Joint attention to each of these components and the specification of their age-related interplays are the conceptual and methodological foundations of the developmental enterprise (PB Baltes et al 1988, Nesselroade 1991, Weinert & Perner 1996).

On a strategic level, there are two ways to construct lifespan theory: person-centered (holistic) and function-centered. The holistic approach (Magnusson 1996, Smith & Baltes 1997) proceeds from consideration of the person as a system and attempts to generate a knowledge base about lifespan development by describing and connecting age periods or states of development into one overall pattern of lifetime individual development. An example would be Erikson's (1959) theory of eight lifespan stages. Often, this holistic approach to the life span is identified with life-course psychology (Bühler 1933; see also Elder 1998). The function-centered way to construct lifespan theory is to focus on a category of behavior or a mechanism (such as perception, information processing, action control, attachment, identity, personality traits, etc.) and to describe the lifespan changes in the mechanisms and processes associated with the category selected. To incorporate both approaches to lifespan ontogenesis in one conceptual framework, the concept of lifespan developmental psychology (PB Baltes & Goulet 1970) was advanced.

Contrary to the American tradition (Parke et al 1991), in Germany Johann Nikolaus Tetens (1777) is considered the founder of the field of developmental psychology (PB Baltes 1983, Müller-Brettel & Dixon 1990, Reinert 1979). From the beginning, the German conception of developmental psychology covered the entire life span and, in its emergence, was closely tied to the role of philosophy, humanism, and education (Bildung). In contrast, the Zeitgeist in North America and some European countries, such as England, was different when developmental psychology emerged as a specialty, around the turn of the twentieth century. At that time, the newly developed fields of genetics and biological evolution were at the forefront of ontogenetic thinking. From biology, with its maturation-based concept of growth, may have sprung the dominant American emphasis in developmental psychology on child psychology and child development. As a consequence, in American psychology a strong bifurcation evolved between child developmentalists, adult developmentalists, and gerontologists.

In recent decades, however, a lifespan approach has become more prominent in North America because of several factors. First was a concern with lifespan development in neighboring social-science disciplines, especially sociology. Life-course sociology took hold as a powerful intellectual force (Elder 1998, Featherman 1983, Mayer 1990, Riley 1987). A second factor was the emergence of gerontology as a field of specialization, with its search for the life-long precursors of aging (Birren & Schaie 1996, Neugarten 1996). A third factor, and a source of rapprochement between child developmentalists and adult developmentalists, was the aging of several classic longitudinal studies on child development begun in the 1920s and 1930s. In the wake of these developments, the need for better collaboration among all age specialties of developmental scholarship has become an imperative of current-day research in developmental psychology (Cairns 1998, Hetherington et al 1988, Rutter & Rutter 1993). But for good lifespan theory to evolve, it takes more than courtship and mutual recognition. It takes a new effort and serious exploration of theory that—in the tradition of Tetens (1777)—has as its primary substantive focus the structure, sequence, and dynamics of the entire life course in a changing society.

THE OVERALL ARCHITECTURE OF LIFESPAN DEVELOPMENT

We approach psychological theories of LP proceeding from the distal and general to the more proximal and specific. The first level of analysis is the overall biological and cultural architecture of lifespan development (PB Baltes 1997, PB Baltes et al 1998). As shown in Figure 1, the benefits of evolutionary selection decrease with age, the need for culture increases with age, and the efficacy of culture decreases with age. The specific form (level, shape) of the functions showing the overall dynamics between biology and culture across the life span is not critical. What is critical is the overall direction and the reciprocal relationship between these functions.

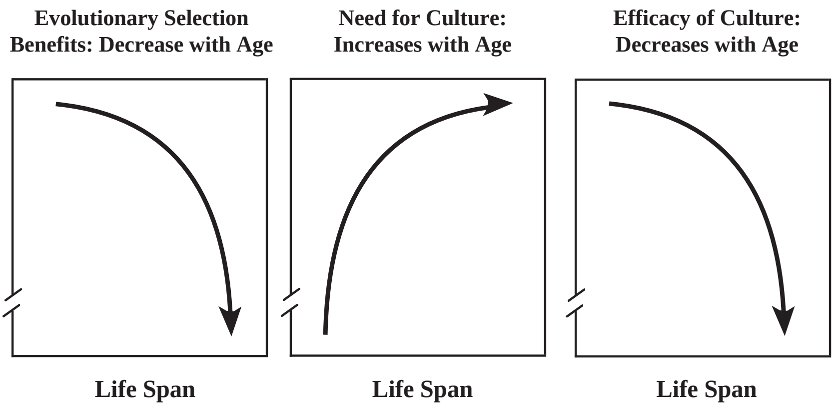

Figure 1 Schematic representation of the average dynamics between biology and culture across the life span (after PB Baltes 1997). There can be much debate about the specific forms of the functions, but less about their direction.

Evolutionary Selection Benefits for the Human Genome Decrease Across the Lifespan

The first component of the tri-partite argument derives from an evolutionary perspective on the nature of the genome and its age-correlated changes in expressivity and biological potential (Finch 1996, Jazwinski 1996, Martin et al 1996): During evolution, the older the organism, the less the genome benefited from the genetic advantages associated with evolutionary selection. In other words, the benefits resulting from evolutionary selection display a negative age correlation. Certainly after maturity, and with age, the expressions and mechanisms of the genome lose in functional quality.

This assertion is in line with the idea that evolutionary selection was tied to the process of reproductive fitness and its location in the first half of the life course. This general statement holds true even though indirect positive evolutionary selection benefits are carried into old age, for instance, through grandparenting (Mergler & Goldstein 1983), coupling, or exaptation (Gould 1984).

This age-associated diminution of evolutionary selection benefits and its implied association with an age-related loss of biological potential was further affected by the fact that in earlier times few people reached old age. Thus, in addition to the negative correlation between age and selection pressure, most people died before possible negative genetic attributes were activated or possible negative biological effects of earlier developmental events became manifest. The relative neglect during evolution of the second half of life is amplified further by other aspects of the biology of aging. For all living systems, there are costs involved in creating and maintaining life (Finch 1996, Jazwinski 1996, Martin et al 1996, Yates & Benton 1995). For instance, biological aging involves wear-and-tear as well as the cumulation of errors in genetic replication and repair.

Age-Related Increase in Need for Culture

The middle part of Figure 1 summarizes the overall perspective on lifespan development associated with culture and culture-based processes. By culture, we mean all the psychological, social, material, and symbolic (knowledge-based) resources that humans have produced over the millennia. These, as they are transmitted across generations in increasing quantity and quality, make possible human development as we know it (Cole 1996, Durham 1991, Valsiner & Lawrence 1997). Among these cultural resources are cognitive skills, motivational dispositions, socialization strategies, literacy, written documents, physical structures, and the world of economics as well that of medical and physical technology.

The argument for an age-related increase in the "need" for culture has two parts. First, for human ontogenesis to have reached higher and higher levels of functioning, whether in physical or psychological domains, there had to be a conjoint evolutionary increase in the richness and dissemination of the resources and "opportunities" of culture (Durham 1991, Valsiner & Lawrence 1997). The farther we expect human ontogenesis to extend itself into adult life and old age, the more necessary it will be for particular cultural factors and resources to emerge to make this possible. Consider, for instance, what happened to average life expectancy and educational status (such as reading and writing skills) in industrialized countries during the twentieth century. The genetic make-up of the population did not change during this time. It is primarily through the medium of more advanced levels of culture including technology that people have had the opportunity to continue to develop throughout longer spans of life.

The second argument for the proposition relates to the biological weakening associated with age. That is, the older we are, the more we need culture-based resources (material, social, economic, psychological) to generate and maintain high levels of functioning. A case in point is that for cognitive efficacy to continue into old age at comparable levels of performance, more cognitive support and training are necessary (PB Baltes & Kliegl 1992, Dixon & Bäckman 1995, Hoyer & Rybash 1994, Salthouse 1991).

Age-Related Decrease in Efficacy of Culture

The third cornerstone of the overall nature of lifespan development is the lifespan script of a decreasing efficacy of cultural factors and resources. During the second half of life, and despite the advantages associated with the developmental acquisition of knowledge-based mental representations (Klix 1993), there is an age-associated reduction in the efficiency of cultural factors, even though large interindividual and interdomain differences exist in onset and rate of these losses in efficiency (Hoyer & Rybash 1994, Lindenberger & Baltes 1997, Nelson & Dannefer 1992, Salthouse 1991, Schaie 1996). The older the adult, the more time and practice it takes to attain the same learning gains. Moreover, at least in some domains of information processing, and when it comes to high levels of performance, older adults may not be able to reach the same levels of functioning as younger adults, even after extensive training and under positive life circumstances (PB Baltes 1997, PB Baltes & Smith 1997, Kliegl et al 1989).

There are two causes for this age-related reduction in cultural efficacy or efficiency. The first is age-related loss in biological potential. The second can be seen by viewing the life course in analogy to a learning curve and the acquisition of expertise (Ericsson & Lehmann 1996). Similar to reduced gains in later phases of learning, more and more effort and better technology are necessary to produce further advances as during development we reach higher levels of functioning. Moreover, there is the possibility of age-related increases in negative transfer and costs of specialized knowledge.

The age-related reduction in cultural efficacy argument is likely to raise objection in some social-science circles (PB Baltes et al 1998, Cole 1996, Lerner 1998a). One objection would be that the specifics of cultural systems, namely its symbolic-representational form, may follow different mechanisms of efficiency. For instance, the lifespan developmental entropy costs of symbolic systems may be less than those observed for basic biological processes. A second objection would be that the concept of efficiency contains assumptions about human functioning which are inherently opposed to phenomena such as meaning of life, a sense of religion, or an understanding of one's finitude. However, such perspectives, important and critical as they are to understanding human development, do not alter the general direction of the lifespan function outlined.

Together, the three conditions and trajectories outlined in Figure 1 form a robust and interrelated fabric (architecture) of the lifespan dynamics between biology and culture. This fabric represents a first tier of lifespan theory (PB Baltes 1997). For evolutionary and historical reasons, the ontogenetic structure of the life course displays a kind of unfinished architecture. Whatever the specific content and form of a given psychological theory of lifespan development, it needs to be consistent with the framework outlined.

LIFESPAN CHANGES IN THE RELATIVE ALLOCATION OF RESOURCES TO VARIOUS GOALS OF DEVELOPMENT

To what degree does the overall architecture of age-related dynamics between biology and culture outlined here prefigure pathways of development and the kind of adaptive challenges that we face as we move through life? One way to understand some of the consequences is to distinguish between three goals of ontogenetic development: growth, maintenance (including resilience), and the regulation of loss. The allocation of available resources for growth, the first of these major adaptive tasks, decreases with age, whereas investments into the latter, maintenance and regulation of loss, increase with age (PB Baltes et al 1998, Staudinger et al 1995).

By growth, we mean behaviors aimed at reaching higher levels of functioning or adaptive capacity. Under the heading of maintenance, we group behaviors aimed either at maintaining levels of functioning in the face of a new challenge or at returning to previous levels after a loss. With the adaptive task of regulation of loss, we identify behaviors that organize adequate functioning at lower levels when maintenance or recovery—for instance because of external or internal losses in resources—is no longer possible.

In our view, the lifespan shift in the relative allocation of resources, away from growth towards the goals of maintenance and the regulation of loss, is a critical issue for any theory of lifespan development (for related arguments, see also Brandtstädter & Greve 1994, Brim 1992, Uttal & Perlmutter 1989). This is true even for those theories that, on the surface, seem to focus only on growth or positive aging (e.g. Erikson 1959, Labouvie-Vief 1995, McAdams & de St. Aubin 1998, Perlmutter 1988, Staudinger 1996). In Erikson's theory, for instance, acquiring generativity and wisdom is the positive developmental goal of adulthood. Despite the growth orientation of these constructs, their attainment is inherently tied to recognizing and managing generational turnover as well as managing or becoming reconciled to one's functional losses, finitude, and impending death.

The dynamics between the lifespan trajectories of growth, maintenance, and regulation should also be emphasized. The mastery of life often involves conflicts and competition among the three goals of human development. Consider, for example, the interplay between autonomy and dependence in children and older adults (MM Baltes 1996, MM Baltes & Silverberg 1994). Whereas the primary focus of the first half of life is the maximization of independence and autonomy, the goal-profile changes in old age. The productive and creative use of dependence rather than independence becomes critical. By invoking dependence and support, older people free up resources for use in other domains involving personal efficacy and growth.

The age-related weakening of the biological foundation and the change in the overall lifespan script associated with growth, maintenance, and regulation of loss does not imply that there is no opportunity for growth at all in the second half of life in some domains. Deficits in biological status can also be the foundation for progress, that is, antecedents for positive changes in adaptive capacity. The most radical view of this proposition is contained in the notion of "culture as compensation." Under the influence of cultural-anthropological as well as evolutionary biological arguments, researchers have recognized that suboptimal biological states or imperfections are catalysts for the evolution of culture and for advanced states achieved in human ontogeny (PB Baltes 1997, Klix 1993, Magnusson 1996, Uttal & Perlmutter 1989). In this line of thinking, the human organism is by nature (Gehlen 1956) a "being of deficits" (Mängelwesen) and social culture has developed or emerged in part to deal specifically with biological deficits.

This "deficits-breed-growth" mechanism may not only account for cultural-biological evolution, it may also affect ontogenesis. Thus it is possible that when people reach states of increased vulnerability in old age, social forces and individuals invest more and more heavily in efforts that are explicitly oriented toward regulating and compensating for age-associated biological deficits, thereby generating a broad range of novel behaviors, new bodies of knowledge and values, new environmental features, and, as a result, a higher level of adaptive capacity. Emerging research on psychological compensation is a powerful illustration of the idea that deficits can be catalysts for positive changes in adaptive capacity (MM Baltes 1996, PB Baltes & Baltes 1990, Brandtstädter 1998, Dixon & Bäckman 1995, Marsiske et al 1995)

METATHEORETICAL AND METHODOLOGICAL PROPOSITIONS WITHIN LIFESPAN PSYCHOLOGY

Development as Change in Adaptive Capacity

From a lifespan theory point of view, it is important to articulate concepts of development that go beyond linear, unidimensional, unidirectional, and unifunctional models, which had flourished in conjunction with the traditional biological conceptions of growth or physical maturation. In these traditional conceptions of development, attributes such as qualitative change, ordered sequentiality, irreversibility, and the definition of an end state were critical.

DEVELOPMENT AS SELECTION AND SELECTIVE ADAPTATION In their conceptual work, lifespan developmentalists attempted either to modulate the traditional definitional approach to development or to offer alternative conceptions of ontogenetic development that departed from the notion of holistic and unidirectional growth, according to which all aspects of the developing system were geared toward a higher level of integration and functioning. Labouvie-Vief (1982, 1992), for instance, introduced new forms (stages) of systemic functioning for the period of adulthood, based on conceptions of development as adaptive transformation and structural reorganization, thereby opening a new vista on neo-Piagetian constructivism.

Baltes and his colleagues (e.g. PB Baltes 1997, PB Baltes et al 1980, 1998) were more radical in their departure from extant theoretical models of development. Considering evolutionary perspectives (PB Baltes 1987, Magnusson 1996), neofunctionalism (Dixon & Baltes 1986), and lifespan contextualism (Lerner 1991), they opted for a more flexible construction of development. One such model was to define development as selective age-related change in adaptive capacity. With the focus on selection and selective adaptation, lifespan researchers were able to be more open about the pathways of life-long ontogenesis. For instance, with this neofunctionalist approach, it becomes possible to treat the developing system as multidimensional, multifunctional, and dynamic, in which differing domains and functions develop in a less than fully integrated manner, and where trade-offs between functional advances and discontinuities between age levels are the rule rather than the exception (see also Brim & Kagan 1980, Labouvie-Vief 1982, Siegler 1997, Thelen & Smith 1998).

DEVELOPMENT AS A GAIN-LOSS DYNAMIC A related change in emphasis advanced in lifespan theory and research was to view development as always being constituted by gains and losses (PB Baltes 1987, PB Baltes et al 1980, 1998, Brandtstädter 1998, Labouvie-Vief 1982). Aside from functionalist arguments, several empirical findings gave rise to this focus.

One example important to lifespan researchers was the differing lifespan trajectories proposed and observed for various components of intelligence (Cattell 1971, Horn & Hofer 1992, Schaie 1994, 1996). For intelligence, throughout the life span gains and losses co-exist. In addition, the open systems view of the incomplete biological and cultural architecture of lifespan development and the multiple ecologies of life made it obvious that postulating a single end state to development was inappropriate. Moreover, when considering the complex and changing nature of the criteria involved in everyday adaptation (which, for instance, across ages differ widely in the characteristics of task demands and outcome criteria; e.g. Berg 1996), the capacity to move between levels of knowledge and skills rather than to operate at one specific developmental level of functioning appeared crucial for effective individual development. Furthermore, the dynamics between gains and losses were highlighted by the phenomenon of negative transfer associated with the evolution of any form of specialization or expertise (Ericsson & Lehmann 1996). As a result, a monolithic view of development as universal growth was rejected as theoretically false and empirically inappropriate.

Recently, one additional concept has been advanced to characterize the nature of lifespan changes in adaptive capacity. This concept is equifinality: As a special case of multifunctionality, the same developmental outcome can be reached by different means and combination of means (Kruglanski 1996, Ribaupierre 1995). The role of equifinality is perhaps most evident in the different ways by which individuals reach an identical level of subjective well-being (Brandtstädter & Greve 1994, Heckhausen & Brim 1997, Smith & Baltes 1997, Staudinger et al 1995). The potential for developmental impact is larger if the resources acquired during ontogenesis carry, in the sense of equifinality and multifunctionality, much potential for generalization and adaptive use in rather different contexts.

Plasticity and Age-Associated Changes

The strong concern of lifespan researchers with intraindividual plasticity (malleability) highlights the search for the potentialities of development, including its upper and lower boundary conditions. Implied in the idea of plasticity is that any given developmental outcome is but one of numerous possible outcomes, and that the search for the conditions and range of ontogenetic plasticity, including its age-associated changes, is fundamental to the study of development.

As lifespan psychologists initiated systematic work on the concept of plasticity, further differentiation of it was introduced. One involved the differentiation between baseline reserve capacity and developmental reserve capacity (PB Baltes 1987, Kliegl et al 1989). Baseline reserve capacity identifies the current level of plasticity available to individuals. Developmental reserve capacity is aimed at specifying what is possible in principle over developmental time if optimizing interventions are employed to estimate future ontogenetic potential. Furthermore, major efforts were made to specify the kind of methodologies that lend themselves to a full exploration of age-related changes in plasticity and its limits (Kruse et al 1993, Lindenberger & Baltes 1995).

Methodological Developments

Metatheory and methodology have been closely intertwined since the very early origins of LP (e.g. Quetelet 1842). Not surprisingly, therefore, the search for methods adequate for the study of developmental processes is a continuing part of the agenda of lifespan researchers (Cohen & Reese 1994, Hertzog 1996, Lindenberger & Baltes 1995, Lindenberger & Pötter 1998, Magnusson 1996, Nesselroade & Thompson 1995).

LIFE EVENTS AND EVENT-HISTORY ANALYSIS One methodological development concerns methods to organize and study the temporal flow, correlates, and consequences of life events. Life-course sociologists, in particular, have made major contributions to the advancement of this methodology. Among the relevant methods, models of event-history analysis and associated methods such as hazard rate and survival analysis are especially important (Blossfeld & Rohwer 1995, Willett & Singer 1991).

One of the critical events for lifespan researchers is mortality or death. As life unfolds from birth into old age, the population itself changes in composition as a result of migration and especially mortality. In advanced old age, for instance, the surviving age cohort becomes smaller and smaller until it reaches zero. Understanding the intricacies of selective survival and its impact on the nature of ontogenetic functions is a serious methodological challenge (for instance, Lindenberger et al 1998).

TESTING THE LIMITS OF PLASTICITY The second example of methodological innovations involves a strategy to examine the scope and limits of plasticity (Kliegl et al 1989, Lindenberger & Baltes 1995). This method is similar to efforts in child development to study the zone of proximal development, for instance, through methods of microgenetic analysis or cognitive engineering (Kuhn 1995, Siegler & Crowley 1991).

Again, because of the long time frame of lifespan ontogenesis, it is difficult to identify the sources and scope of plasticity and its age-related changes. At the same time, the inquiry into what is possible in principle in human development across the life span is important. One example is the perennial question of cognitive-aging researchers about whether aging losses in functions reflect experiential practice deficits rather than effects of biological aging. In testing-the-limits research (Kliegl et al 1989, Lindenberger & Baltes 1995), the goal is to compress time by providing for high-density developmental experiences; and, by doing so, to identify asymptotes of performance potential (plasticity). These asymptotes, obtained under putatively optimal conditions of support, are expected to estimate the upper range of the age-specific developmental potentiality, comparable to the traditional notion of the upper limit of the "norm of reaction."

Testing-the-limits research and related strategies of developmental simulation, however, are relevant not only for the study of long-term ontogenetic processes, but also for other important aspects of developmental research and theory, for example the question of inherited differences in cognitive functioning (Lerner 1995, Plomin 1994). Much of the work on behavior genetics is essentially descriptive and based on ex post analysis. Based on the premise that knowledge about differences in asymptotic levels of functioning is crucial, we need to depart from simple, noninterventive comparative research and to invest scientific resources into testing-the-limits work: to expose smaller samples of participants to time-compressed experiential interventions and to search for interindividual differences between identical and fraternal twins at the upper or lower levels of functioning (see also PB Baltes 1998a, Fox et al 1996, Kruse et al 1993).

A SYSTEMIC THEORY OF LIFESPAN DEVELOPMENT: SELECTIVE OPTIMIZATION WITH COMPENSATION

During the recent decade, several efforts at theoretical development in lifespan psychology have emanated from both child-adolescent researchers (e.g. Hetherington et al 1988, Lerner 1998a, Rutter & Rutter 1993) and the community of researchers on aging (e.g. Schroots 1996). For the present purpose, with its emphasis on exploring consistency and fertility between levels of analysis, we focus on a theory of development, selective optimization with compensation, that Margret Baltes, Paul Baltes and their colleagues have developed (MM Baltes & Carstensen 1996, PB Baltes 1997, PB Baltes & Baltes 1990, PB Baltes et al 1984, Freund & Baltes 1998, Marsiske et al 1995; see also Carstensen 1995, Featherman et al 1990, Heckhausen & Schulz 1995, Schulz & Heckhausen 1996).

Successful development is defined in this theoretical approach as the conjoint maximization of gains (desirable goals or outcomes) and the minimization of losses (undesirable goals or outcomes). The nature of what constitutes gains and losses, and of the dynamic between gains and losses, is conditioned by cultural and personal factors as well as by the position in the lifetime of an individual. Thus an achieved developmental outcome can at a later ontogenetic time or in a different context be judged as dysfunctional. Moreover, what constitutes a gain and what a loss also depends on whether the methods used to define it are subjective or objective (MM Baltes & Carstensen 1996, Heckhausen & Schulz 1995).

The theory SOC is both universal and relativistic. In its metatheoretical universality, it postulates that any process of human development involves an orchestration of selection, optimization, and compensation (Figure 2). In its concrete theoretical specification, however, processes of SOC are person-specific and contextually bound. Thus, as the theoretical model is applied to specific domains and contexts of psychological functioning (such as control, autonomy, and professional expertise, or to different cultural contexts), it requires further specification to be derived from the knowledge base of the domain of functioning selected for application and for the context in which this phenomenon is embedded (e.g. Abraham & Hansson 1995, MM Baltes & Lang 1997, Freund & Baltes 1998, Heckhausen & Schulz 1995, Marsiske et al 1995).

Definition of Selection, Optimization, and Compensation

An everyday example may help to clarify the meaning of SOC (PB Baltes & Baltes 1990). When the concert pianist Arthur Rubinstein, as an 80-year-old, was asked in a television interview how he managed to maintain such a high level of expert piano playing, he hinted at the coordination of three strategies.

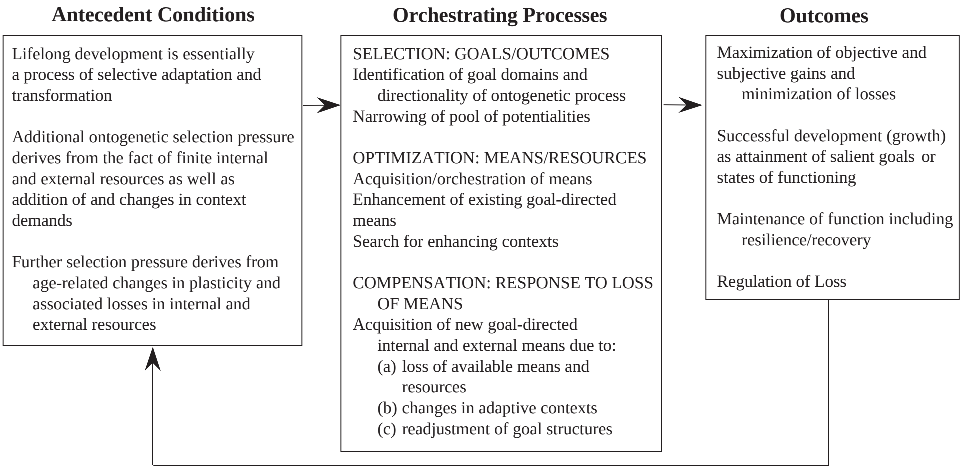

Figure 2 The lifespan model of selective optimization with compensation. The essentials of the model are proposed to be universal, but specific phenotypic manifestations will vary by domain, individual, sociocultural context, and theoretical perspective (adapted from PB Baltes 1987, 1997, PB Baltes &Baltes 1990, Marsiske et al 1995).

First, he played fewer pieces (selection); he practiced these pieces more often (optimization); and to counteract his loss in mechanical speed he now used a kind of impression management, such as playing more slowly before fast segments to make the latter appear faster (compensation).

The specific definitions of selection, optimization, and compensation are conditioned by the theoretical framework chosen. Within an action-theoretical framework, for instance, the following characterizations hold: Selection involves goals or outcomes; optimization involves goal-related means to achieve success (desired outcomes); and compensation involves a response to loss in goal-relevant means in order to maintain success or desired levels of functioning (outcomes). Each of the processes can be active or passive, conscious or subconscious, internal or external.

SELECTION Selection involves directionality, goals, and outcomes. Strictly speaking, selection already begins in embryonic development. For instance, neurophysiological processing of information represents a fundamental example of selection and selection-based specialization (Edelman & Tononi 1996, Siegler 1997).

During ontogeny, there are several additional sources for selection. First is the goal and outcome orientation of development. Individuals and societies sample from a population of possibilities or opportunities and evolve specific articulations and differentiations of goal structures. A second source is limited individual capacity in time and resources. The third source is the incompatibility of goals and outcomes. A fourth source is age-related changes in plasticity or basic potential. Because of the different conditions of selection, it is also useful to distinguish between two kinds of selection: Elective and loss-based selection (Freund & Baltes 1998). Elective selection is assumed to be primarily the result of a prepared module-driven and motivation-driven selection from a number of possible pathways. Loss-based selection results from the unavailability of outcome-relevant means or resources.

OPTIMIZATION The focus of optimization is on the acquisition, refinement, and maintenance of means or resources that are effective in achieving desirable outcomes and avoiding undesirable ones. In general, and at a systemic level, optimization requires a mutually enhancing coalition of factors, including health, environmental, and psychological conditions such as goal investment and goal pursuit (Brandtstädter 1998, Gollwitzer & Bargh 1996, Marsiske et al 1995, Staudinger et al 1995). The most domain-general notion of optimization is the generation of developmental reserve capacity in the sense of a set of general-purpose mechanisms (PB Baltes et al 1998, Staudinger et al 1995). The development of a certain personality profile can also be considered a case of optimization (Staudinger & Pasupathi 1998).

COMPENSATION Compensation involves a functional response to the loss of an outcome-relevant means (see also Brandtstädter & Wentura 1995, Dixon & Bäckman 1995). There are two major functional categories of compensation. The first is to enlist new means as strategies of compensation to reach the same goal. The second compensatory strategy concerns means to change goals of development in response to loss of goal-relevant means (PB Baltes & Baltes 1990, Brandtstädter & Wentura 1995, Heckhausen & Schulz 1995).

Three main causes give rise to a compensatory situation (Marsiske et al 1995). A first is conditioned by the very fact of selection and optimization. Because time and effort have limits, selection of and optimization toward a given goal can imply the loss of means relevant for the pursuit of other goals. Negative transfer from the acquisition of one expert skill system to another is another possible result of selection and optimization (Ericsson & Lehmann 1996).

A second category of causes of compensation stems from environment-associated changes in resources. Changing from one environment to another may involve a loss in environment-based resources (means) or may make some acquired personal means dysfunctional. The third category of causes resulting in a situation of compensation are losses in means due to age-associated declines in plasticity associated with the biology of aging and the lifespan structure of societal opportunities that, for instance, is less developed for later life. Such normative age-associated decline in biology-based plasticity and environment-based opportunity can be accelerated further by nonnormative events such as accidents or illnesses. In each of these instances, the central issue is a loss in outcome-relevant means.

Distinguishing between these categories of causes for compensation is not always easy (Dixon & Bäckman 1995, Freund & Baltes 1998, Marsiske et al 1995). The principles of multicausality, equifinality, and multifunctionality suggest that multiple antecedent and outcome criteria can be involved. Moreover, the categorical status of a given event is likely to change. For instance, as compensatory responses become automatic they can then be used for other purposes such as optimization. Indeed, it is central to the temporal and sequential dynamics of ontogenetic development that the logical status of selection, optimization, and compensation varies. Nevertheless, their collaborative function is always to achieve “successful development” as defined above.

Selective Optimization with Compensation: Orchestration and Dynamics in Development

Without specifying the substantive goals and outcomes of development, then, the SOC model is intended to characterize the processes that in their coordinated orchestration result in desired outcomes of development while minimizing undesirable ones. One recent illustration (Freund & Baltes 1998) is research showing that individuals who report using SOC strategies also report higher levels in subjective indicators of successful aging.

Depending on which level of analysis is chosen (societal, individual, microbehavioral, etc.), SOC requires the use of a different lens for different levels of measurement and specification. For instance, at a biographical level of analysis and everyday competence (MM Baltes & Lang 1997), the lens might focus on the interplay among cognitive, physical, sensory, and motor functioning. But when studying cognitive reserve capacity, for instance by means of dual-task or parallel-task processing, the lens might focus on the SOC-related interplay between components of working memory and other attentional resources (U Lindenberger, M Marsiske, PB Baltes, submitted manuscript).

The model of selective optimization with compensation is but one of the theoretical efforts that lifespan research and theory have spawned. However, the SOC model displays much consistency across levels of analysis and can be usefully linked to other current theoretical streams in developmental psychology, such as dynamic systems theory (Magnusson 1996, Thelen & Smith 1998). Moreover, the study of the orchestration of the processes of selection, optimization, and compensation is a promising strategy toward understanding how effective human development emerges, and how lifespan developmental changes in resources, contexts, and challenges require an adaptive reorganization and transformation of means and ends (MM Baltes & Carstensen 1996, PB Baltes et al 1998, Heckhausen & Brim 1997, Schulz & Heckhausen 1996).

THE TWO–COMPONENT MODEL OF LIFESPAN INTELLECTUAL DEVELOPMENT

The usefulness of LP depends critically on examining the degree of convergence between the theoretical propositions regarding the macroscopic overall landscape of the entire course of ontogeny and more microscopic research on developmental functions, processes, and age periods. Currently, perhaps no other field within developmental psychology is better suited to test this correspondence than the field of intellectual development.

The lifespan concepts of multidimensionality and multidirectionality permit the charting of differing trajectories of intellectual functioning across the life span (cf. Cattell 1971, Horn & Hofer 1992). In this vein, a lifespan theory of intellectual development has been proposed that distinguishes between two main categories or components of intellectual functioning: The mechanics and the pragmatics of cognition (PB Baltes 1987, 1997, PB Baltes et al 1984). As illustrated in Figure 3, the mechanics of cognition are construed as an expression of the neurophysiological architecture of the mind (McClelland 1996, Singer 1995) as it evolved during biological evolution (cf. Tooby & Cosmides

1995) and unfolds during ontogenesis (Rakic 1995). In contrast, the pragmatics of cognition are associated with acquired bodies of knowledge available from and mediated through culture. Thus, in accordance with our view of the overall architecture of human development, the two-component model locates intellectual development within biological and cultural systems of inheritance or "co-evolution" (Durham 1991).

Empirical evidence in support of the two–component model comes from a great variety of research traditions (PB Baltes et al 1998). Probably the most longstanding supportive evidence is the difference between maintained and vulnerable intellectual abilities (Jones & Conrad 1933, PB Baltes & Lindenberger 1997, Salthouse 1991, Schaie 1994, 1996). Abilities that critically involve mechanics, such as reasoning, spatial orientation, or perceptual speed, generally show monotonic and roughly linear decline during adulthood, with some further acceleration of decline in very old age. In contrast, more pragmatic abilities, such as verbal knowledge (e.g. semantic memory) and certain facets of numerical ability, have weak, and sometimes positive, age relations up to the sixth or seventh decade of life, and start to decline only in very old age. Figure 4 illustrates for the case of old age the fact that, as suggested by the overall architecture of the life course and the two-component model, the cognitive mechanics and the cognitive pragmatics are regulated differentially by cultural and biological factors, and that in late life the role of biological factors becomes stronger.

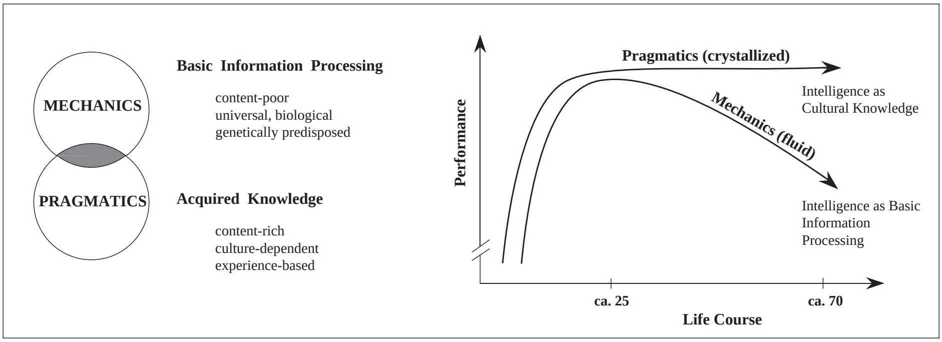

Figure 3 Lifespan research on two components of cognition, the fluid mechanics and the crystallized pragmatics. The *left panel* defines the categories; the *right panel* illustrates postulated lifespan trajectories (after PB Baltes et al 1998; cf. Cattell 1971, Hebb 1949, Horn & Hofer 1992).

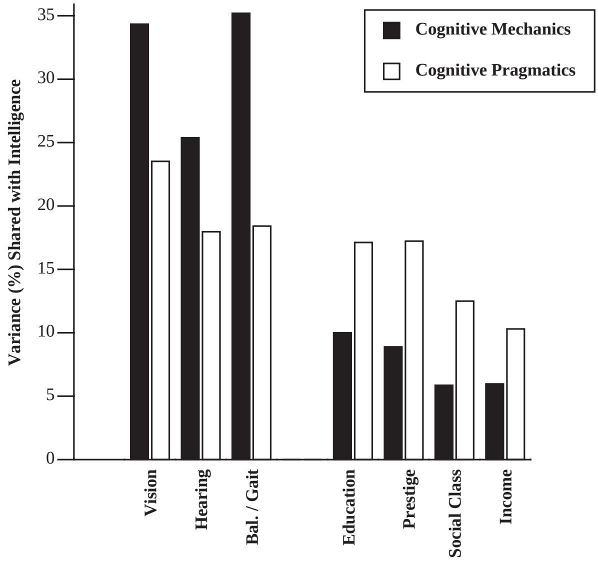

Figure 4 Explanatory sources of intellectual functioning in very old age provide support for the two-component model of lifespan intellectual development and lifespan changes in the relative importance of cultural vs. biological determinants of individual differences. The figure displays differential correlational links of perceptual speed, a marker of the cognitive mechanics, and verbal knowledge, a marker of the cognitive pragmatics, to indicators of socio-biographical life history and biological (e.g. sensory-motor) status. Perceptual speed is more highly correlated with biological indicators than verbal knowledge, and verbal knowledge is more highly correlated with socio-biographical indicators than perceptual speed. At the same time, both are more strongly related to biological than to socio-biographical indicators, reflecting aging-induced changes in the functional integrity of the brain. Data are taken from the Berlin Aging Study (N = 516, age range = 70–103 years). Lindenberger & Baltes 1997.

THE TWO–COMPONENT MODEL: RELATIONS TO OTHER THEORIES The closest relative, both conceptually and historically, to the two-component model of lifespan intellectual development is the psychometric theory of fluid (Gf) and crystallized (Gc) abilities (Cattell 1971, Horn & Hofer 1992). Other approaches related to the two-component model include Hebb's (1949) distinction between intelligence A (intellectual power) and intelligence B (intellectual products), Ackerman's (1996) PPIK (process, personality, interests, and knowledge) theory, and the encapsulation model of adult intelligence (Hoyer & Rybash 1994). In addition, Hunt (1993) offered an information-processing reinterpretation of the Gf-Gc theory that resonates well with the two–component model (see also Welford 1993).

The Mechanics of Cognition

In cognitive-intellectual operations, we assume that the cognitive mechanics are indexed by the speed, accuracy, and coordination of elementary processing operations. In these mechanics of cognition, biological (e.g. brain-related) conditions reign supreme, and the predominant lifespan pattern shows maturation, stability, and aging-induced decline.

Early in ontogeny (i.e. during embryogenesis, infancy, and early childhood), age changes in the mechanics are assumed to reflect, for the most part, the unfolding and active construction of more or less domain-specific and predisposed processing capabilities (Karmiloff-Smith 1995, Wellman & Gelman 1992). In contrast, negative age changes in the mechanics of cognition late in life presumably reflect brain aging as well as the pathological dysfunctions resulting from aging-associated insults to the brain (cf. Martin et al 1996, Morrison & Hof 1997).

THE SEARCH FOR LIFESPAN DETERMINANTS OF THE COGNITIVE MECHANICS

Researchers in the fields of both child development (e.g. McCall 1994) and aging (e.g. Birren & Fisher 1995, Cerella 1990) have been trying to identify developmental determinants or "developables" (Flavell 1992) that regulate the rate of age-based changes in cognitive and intellectual functioning. In addition, some investigators have linked research from both ends of the age spectrum to arrive at lifespan comparisons of the structure and efficiency of information processing (e.g. Dempster 1992, Kail & Salthouse 1994, Mayr et al 1996, Ribaupierre 1995).

So far, three constructs have been studied most extensively as regulators of development in the cognitive mechanics: (*a*) *Information processing rate* (Salthouse 1996), or the speed with which elementary processing operations can be executed (child development: Fry & Hale 1996, Rose & Feldman 1997; aging: Park et al 1996, Verhaeghen & Salthouse 1997), (*b*)*Working memory* (Baddeley 1996, Just et al 1996), or the ability to preserve information in one or more short-term stores while simultaneously transforming the same or some other information (child development: Mayr et al 1996, Miller & Vernon 1996, Swanson 1996; aging: Fisk & Warr 1996, Kirasic et al 1996, Mayr et al 1996, Verhaeghen & Salthouse 1997), and (*c*) *Inhibition* (Bjorklund & Harnishfeger 1995, Zacks & Hasher 1997), or the ability to automatically inhibit or intentionally suppress the processing of goal-irrelevant information (child development: McCall 1994, Ridderinkhof & van der Molen 1995; aging: Zacks & Hasher 1997, Stoltzfus et al 1996).

Currently, the information processing rate, especially if measured with psychometric tests of perceptual speed, seems to be the strongest mediator of age differences in the mechanics of cognition in childhood (Fry & Hale 1996), adulthood (Verhaeghen & Salthouse 1997), and old age (Lindenberger et al 1993). It is however unclear whether perceptual speed represents a "processing primitive" in the sense of information processing rate, or a complex construct with substantial contributions from working memory (Graf & Uttl 1995) and more basic sensory functioning (PB Baltes & Lindenberger 1997, Lindenberger & Baltes 1994). The explanatory power of the working-memory construct, in turn, is also difficult to judge. First, age-based changes in working memory are often described by alluding to changes in processing speed (Case 1985) or inhibition (Brainerd 1995, Stoltzfus et al 1996). Second, an essential function of working memory consists in the goal-directed control of action and thought (Duncan et al 1996, Grafman et al 1995). This complex function puts working memory at the center of intelligent behavior and raises doubts about its status as a "processing primitive" or "basic determinant" of intellectual development. Finally, the curvilinear lifespan age gradients observed with typical measures of interference proneness (e.g. the Stroop color-word test) may reflect age changes in changes in processing rate (Salthouse & Meinz 1995), selective attention (Plude et al 1994), or discrimination learning (Hartman 1995), rather than age changes in inhibitory functioning.

These difficulties in identifying determinants of developmental change in the mechanics of cognition have led to productive discussions at the interface of multivariate-psychometric, cognitive-experimental, and radically reductionist approaches (Cerella 1990, Hertzog 1996, Kliegl et al 1994, Lindenberger & Baltes 1994, Perfect 1994, Rabbitt 1993). Future research on this topic is likely to profit also from closer contact with the neurosciences (Gazzaniga 1995) and the careful examination of the systemic properties of developing brains (Fischer & Rose 1994, Nelson & Bloom 1997, Thatcher 1994) as well as a heightened awareness for interindividual differences in intraindividual change (Fischer et al 1992, Ribaupierre 1995, Schneider & Sodian 1997; cf. Nesselroade 1991).

PURIFICATION OF MEASUREMENT One problem of age-comparative research of intellectual functioning is that much of our knowledge about the lifespan trajectory of the mechanics of cognition is based on imprecise indicators. Age differences and age changes in measures of the cognitive mechanics are influenced by a wealth of additional but extraneous factors, such as pre-assessment differences in practice, task-relevant knowledge, and person characteristics such as test anxiety or arousal. A likely indication for this admixture of pragmatic variance to supposedly mechanical measures is the secular rise in performance on typical psychometric marker tests of fluid intelligence (cf. Flynn 1987, Schaie 1996). As a consequence of ability-extraneous performance factors, individuals' cognitive performance under standard testing conditions represents just one possible phenotypic manifestation of their range of performance potential. In our view, to separate the possible from the impossible over age, the context of measurement needs to be moved toward the upper limits of performance potential.

Within LP, and as mentioned earlier, testing-the-limits has been introduced as a research strategy to uncover adult age differences in the upper (asymptotic) limits of mechanical functioning. The main focus of this paradigm is to arrange for experimental conditions that produce maximum (i.e. asymptotic) levels of performance. In such research, robust age differences were identified. For instance, after 38 sessions of training in a memory technique, not a single older adult was performing above the mean of the young adults (PB Baltes & Kliegl 1992, Kliegl et al 1989). It appears worthwhile to intensify the use of the testing-the-limits paradigm with lower age groups to obtain genuine lifespan gradients regarding maximum limits of performance potential in different domains. Our prediction is that lifespan peaks are shifted toward younger ages whenever cognitive tasks of the mechanics are freed from pragmatic, that is, knowledge- and experience-based influence. Also, cohort differences in the cognitive mechanics will become smaller if efforts are made to test individuals at their asymptotic limits of performance potential.

The Pragmatics of Cognition

In contrast to the mechanics, the pragmatics of cognition direct the attention of lifespan developmentalists toward the role of culture and the increasing importance of knowledge-based forms of intelligence as human ontogeny evolves (Ackerman 1996, PB Baltes 1997, Ericsson & Lehmann 1996, Marsiske & Willis 1998). Positive developmental changes in the pragmatic component reflect the acquisition and lifelong practice of culturally transmitted bodies of declarative and procedural knowledge that are made available to individuals in the course of socialization and lifetime experiences. Some of the lifetime experiences leading to the acquisition of pragmatic knowledge are normative but specific to certain cultures (e.g. formal schooling), others are more universal (e.g. mentoring), and still others are idiosyncratic or person-specific (e.g. specialized ecological and professional knowledge).

We assume that the pragmatics of cognition build on, extend, and reorganize prestructured core domains (Wellman & Gelman 1992) associated with the cognitive mechanics and their foundation in the biological nature of the human processing system (Saffran et al 1996, Smotherman & Robinson 1996, Spelke et al 1995). For instance, pragmatic knowledge may evolve from or mimic predisposed knowledge in evolutionarily privileged domains, but come with the advantage of being tuned to the idiosyncratic demands of specific cultures, biographies, and contexts (Siegler & Crowley 1994). These processes of extension and transformation eventually give rise to forms of knowledge and behavior that are, in part by virtue of necessity, compatible with the biological architecture of the mind, but that are not the direct consequence of evolutionary selection pressures.

NORMATIVE AND PERSON-SPECIFIC PRAGMATIC KNOWLEDGE An important, albeit necessarily imperfect, distinction within the pragmatics of cognition concerns normative versus person-specific knowledge. Normative bodies of knowledge are of general value, either across or within cultures. Typical examples include language proficiency as indexed by verbal abilities, number proficiency, and basic knowledge about the world. Individual differences in these domains are closely linked to years of education and other aspects of social stratification, and are well captured by psychometric testing and theorizing (Cattell 1971, Carroll 1993, Horn & Hofer 1992).

Person-specific bodies of knowledge that branch off from the normative knowledge-acquisition path result from specific combinations of experiential settings, personality characteristics, motivational constellations, action-control strategies, and cognitive abilities or talent (Marsiske et al 1995). As a consequence, these idiosyncratic bodies of knowledge often escape psychometric operationalization and are better amenable to study within the expertise paradigm (Ericsson & Lehmann 1996) or other conceptions of everyday cognitive functioning (Marsiske & Willis 1998, Smith 1996, Staudinger & Pasupathi 1998).

Two main conclusions can be drawn from lifespan research within the expertise paradigm. First, expertise effects, or the consequences of specific bodies of declarative and procedural knowledge, rarely transcend the boundaries of the target domain. Specifically, there is little evidence to suggest that the mechanics of cognition are altered in themselves by domain-specific knowledge (Krampe & Ericsson 1996, Salthouse 1991). The second major conclusion concerns the power of pragmatic knowledge to make up for losses in the mechanics within the domain of expertise (Bosman & Charness 1996, Hess & Pullen 1996, Krampe & Ericsson 1996). Here, the results from several studies suggest that acquired knowledge endows aging individuals with a local (e.g. domain-bound) ability to withstand the consequences of aging-induced losses in the mechanics. Negative adult age differences, compared with standard psychometric or cognitive-experimental assessments, tend to be attenuated in knowledge-rich domains of everyday relevance, such as practical problem solving (Berg 1996, Marsiske & Willis 1995), social cognition (Blanchard-Fields & Hess 1996), memory in collaborative contexts (Dixon & Gould 1996, Hess & Pullen 1996), life planning (Smith 1996, Staudinger 1998), wisdom (PB Baltes & Staudinger 1993, Staudinger 1996), interactive-minds cognition (PB Baltes & Staudinger 1996), and card playing (Charness & Bosman 1990, Knopf et al 1995). This finding of attenuated negative age differences is of central importance for successful intellectual aging, and supports the general lifespan theory of selective optimization with compensation (MM Baltes & Carstensen 1996, PB Baltes 1997).

INTELLECTUAL GROWTH DURING ADULTHOOD: STAGE CONCEPTIONS VERSUS FUNCTIONALIST APPROACHES An important debate within lifespan intellectual development refers to the question of (*a*) whether adult intellectual development follows a structuralist, stage-like logic, and can be described as a movement toward higher forms of reasoning and thought (Alexander & Langer 1990, Labouvie-Vief 1992, 1995); or (*b*) whether functionalist approaches (Dixon & Baltes 1986) emphasizing the local nature of developmental adaptations, as they prevail in the study of knowledge acquisition, selective specialization, and transfer, provide a better, or at least more parsimonious description of adult intellectual growth. Much of the search for stage-like development during adulthood has been inspired by Piaget's theory of cognitive development (Chapman 1988, Pascual-Leone 1995), and it has tried to identify one or more "post-formal" or "dialectical" stages of cognitive development after the advent of formal operations. The conceptual description of these stages often connects personality development (e.g. Eriksonian generativity, reflexivity) with logical considerations (e.g. awareness and acceptance of contradiction; see PB Baltes et al 1998, McAdams & de St. Aubin 1998, Staudinger & Pasupathi 1998). Supporting evidence has been scarce, which is not surprising given the general difficulties in obtaining indicators of stage-like cognitive change (cf. van der Maas & Molenaar 1992).

Despite his constructivist and dialectical epistemology, Piaget himself was reluctant to posit any stages beyond formal operations. Instead, he argued, on one occasion at least (Piaget 1972), that late adolescents and adults would exhibit formal-operational reasoning within their areas of expertise but not necessarily across all domains of knowledge. This view seems consistent with the two-component model of cognition, because the potential for adult intellectual growth is linked to factors operating within rather than across domains (e.g. acquisition of pragmatic knowledge). Thus, in our functionalist view, the structuralist search for higher forms of reasoning can be reframed as the search for bodies of factual and procedural knowledge with a high degree of generality and meaning. In full agreement with the intent of structuralist theorizing on adult intellectual development, the acquisition of such bodies of knowledge is assumed to counteract the lifespan tendency toward fragmentation (Stich 1990) and specialization induced by less general bodies of knowledge.

WISDOM AS EXAMPLE In the context of growth in adulthood involving the cognitive pragmatics, wisdom has been proposed as a prototypical example (PB Baltes et al 1984, Clayton & Birren 1980, Sternberg 1990). In the Neo-Piagetian tradition, wisdom has been related to the postformal stage of thought (e.g. Labouvie-Vief 1992). In the functionalist lifespan tradition, wisdom has been conceived as the optimal expression of knowledge in the fundamental pragmatics of life, that is, expert and integrative knowledge about the meaning and conduct of life and ways to coordinate mind, personality, and emotion (PB Baltes et al 1998, Blanchard-Fields & Hess 1996, Staudinger 1998, Staudinger & Pasupathi 1998). Indeed, the observed absence of negative adult age differences in wisdom-related performance up to about age 75 and the fact that life experiences such as professional specialization (Smith et al 1994) modulate the level and direction of age gradients stand in contrast to the ubiquity of negative and robust adult age gradients in the cognitive mechanics. In addition, of the top performances in wisdom tasks, a large number come from people in late adulthood (PB Baltes et al 1995). Only in very old age do the mechanics seem to delimit wisdom-related performance, probably because they fall below a critical threshold of functional integrity (PB Baltes et al 1995; cf. Pratt et al 1996, Smith & Baltes 1997).

Originally, research on wisdom was motivated primarily by the search for positive aspects of human aging. Meanwhile, this intellectual agenda has been extended to include aspects of clinical psychology (Smith et al 1994), cultural psychology (Staudinger 1996), and the cognitive psychology of heuristics. As to the latter, Baltes (1998) argues that wisdom is a cognitive and motivational metastrategy that orchestrates diverse bodies of knowledge toward human excellence. As such a high-level heuristic about the conduct of life, wisdom (*a*) protects against the fragmentation of knowledge (Stich 1990) and (*b*) enhances the control of one's vices and the optimization of one's virtues. In this sense, wisdom is a lifetime general-purpose heuristic aimed at the well-being of oneself and that of others.

Mechanic/Pragmatic Interdependence

The mechanics and pragmatics of lifespan intellectual development are intertwined to varying degrees and at various levels of analysis (cf. Bosman & Charness 1996). Phylogenetically, they are connected in the sense that members of the human species are biologically predisposed to acquire cultural knowledge in the sense of co-evolution (cf. Durham 1991, Klix 1993). Ontogenetically, the interdependence is bidirectional as well.

On the one hand, the potential to acquire and use pragmatic knowledge is constrained by age-based changes in the potential and status of the mechanical component (Elbert et al 1995). The mechanics of cognition condition not only the acquisition of pragmatic knowledge, but also its expression (Bosman & Charness 1996, Molander & Bäckman 1996). On the other hand, the pragmatics of cognition provide the medium (content) and, at least during the first tier of life, the structure for the phenotypic unfolding of the cognitive mechanics. Furthermore, the pragmatics of cognition serve to optimize levels of performance in content-rich and evolutionarily nonprivileged domains of intellectual functioning, as research on expertise (Ericsson & Lehmann 1996), wisdom, and on other domains involving interactive minds (PB Baltes & Staudinger 1996) has convincingly demonstrated. As a consequence, pragmatic knowledge helps to counteract the limitations of the mechanics (Gobet & Simon 1996), including the negative consequences of age-based losses (Thompson 1995).

Plasticity (Malleability) in Intellectual Functioning Across Historical and Ontogenetic Time: Evidence from Adult Development

As noted before, lifespan changes in intellectual functioning are determined by a large variety of different sources of influence. As a consequence, differences in level of intellectual performance are influenced, within the age-graded boundaries provided by the mechanics, by variations in the physical or sociocultural aspects of environmental conditions that in turn are associated with differences in life histories of cognitive experience (Schaie 1996, Willis et al 1997). The systematic analysis of environmental-change influences on intellectual development at varying levels of generality and temporal extension has helped to highlight the plasticity (malleability) of intellectual functioning, including its age-associated changes.

COHORT EFFECTS, PERIOD EFFECTS, AND ENVIRONMENTAL CHANGE Levels and forms of age gradients in intellectual abilities are shaped, to varying degrees, by history-graded systems of influence, such as enduring differences between people born at different points in historical time (cohort effects), specific influences of historical events across chronological age (period effects), or generalized and enduring shifts in the environment affecting individuals of all ages and subsequent cohorts (general environmental change). Discriminating among these varieties of environmental change is not easy (PB Baltes et al 1988, Magnusson et al 1991, Schaie 1996).

A first step to discern effects of large-scale environmental change is to compare the performance of same-aged individuals across historical time (i.e. time-lag comparisons). With some exceptions (e.g. number ability; cf. Schaie 1996), the general picture resulting from such comparisons is that higher test scores have been obtained in more recent times (Flynn 1987, Schaie 1996). Probably this increase in test scores across time reflects improvements in health-related, education-related, and work-related conditions. Such culturally based cohort effects were instrumental in pointing to the substantial malleability (plasticity) of intellectual performance during all periods of the adult life span.

Studies with cohort-sequential designs allow three kinds of comparisons across age: cross-sectional, longitudinal, and independent-sample same-cohort comparisons (e.g. age comparisons based on independent samples from the same birth cohort). In the case of the Seattle Longitudinal Study (Schaie 1994, 1996), independent-sample same-cohort and cross-sectional comparisons yielded highly similar estimates of a seven-year change after the analysts controlled for the general increase in performance over historical time revealed by time-lag comparisons (Salthouse 1991). In contrast, longitudinal age changes, also corrected for historical change, showed a somewhat smaller decrement with age. Given the convergence between cross-sectional and independent-sample same-cohort comparisons, the more positive age gradients found with longitudinal samples may be partly due to practice effects and selective attrition.

COGNITIVE INTERVENTION WORK: ACTIVATION OF LEARNING POTENTIAL AMONG OLDER ADULTS Experimentally controlled interventions explore the degree of plasticity in intellectual functioning more directly than does cohort-comparative research (PB Baltes 1993, Willis & Schaie 1994). The evidence of the powerful role of experience and practice in the acquisition, refinement, and maintenance of the cognitive pragmatics is overwhelming (PB Baltes et al 1998, Ericsson & Lehmann 1996, Hoyer & Rybash 1994). Here the review focuses on cognitive intervention work with older adults associated with the study of psychometric intelligence and related tasks that are closer to the cognitive mechanics, such as tests of fluid intelligence. The main results can be summarized in seven points: (*a*) Training gains in the practiced tests among healthy older adults are substantial (e.g. they roughly correspond to the amount of average "natural" longitudinal decline between 50 and 70 years of age); (*b*) transfer, however, is limited to similar tests of the same ability; (*c*) gains observed as a function of self-guided practice are of similar magnitude as gains resulting from tutor-guided practice; (*d*) training gains are maintained over lengthy periods of time up to several years (Stigsdotter Neely & Bäckman 1993, Willis & Schaie 1994); (*e*) the factor structure of the ability space is not altered substantially through training (Schaie et al 1987); (*f*) the amount of training gain is substantially reduced as people reach advanced old age (Lindenberger & Baltes 1997); and (*g*) in persons at risk for Alzheimer's disease or afflicted by other forms of brain pathology, learning gains are substantially reduced (Grober & Kawas 1997) or nonexistent (MM Baltes et al 1995). At limits of functioning and in advanced old age, older adults definitely display less potential for gains from training (PB Baltes & Kliegl 1992, Lindenberger & Baltes 1997).

These results indicate that cognitive plasticity in the mechanics of cognition is preserved among healthy older adults and is easily activated through experiential manipulations (cf. Woodruff-Pak 1993, for relevant neurophysiological evidence). Nevertheless, the general lack of transfer of training to related abilities or to everyday functioning suggests the hypothesis that performance improvements in tests of fluid intelligence primarily reflect changes in pragmatic components of performance potential, rather than improvements in the cognitive mechanics themselves.

Relative Stability of Intellectual Functioning Across the Lifespan

Most of the evidence on relative stability after infancy, that is, stability across age in interindividual differences, is based on undifferentiated measures of intelligence (e.g. IQ tests). Such measures can be seen as mixtures of mechanical and normative–pragmatic components of intellectual functioning that approximate, to varying degrees, the centroid of the intellectual ability factor space (i.e. Spearman's *g*; see also Horn 1989). With this qualification in mind, we restrict the following discussion, with the exception of infant development, to undifferentiated (e.g. IQ-like) measures of intellectual functioning.

PREDICTING CHILDHOOD INTELLIGENCE ON THE BASIS OF INFANT BEHAVIOR In contrast to earlier findings using standard tests of infant development, research using habituation and recognition-memory paradigms (Bornstein 1989, McCall & Carriger 1993) has revealed a sizable degree of stability in interindividual differences between infant behavior and childhood intelligence. On average, individual differences in habituation and recognition memory performance in infants between the ages of 2 and 8 months are moderately correlated with standard tests of intelligence such as the Wechsler, Bayley, or Binet, administered between 1 and 8 years of age (median correlation, $r = .45$; after attenuation for unreliability, $r = .70$; cf. Bornstein 1989, McCall & Carriger 1993). Thus, both change in and stability of individual differences are important aspects of lifespan intellectual development from its very beginning.

RELATIVE INTERINDIVIDUAL STABILITY AFTER INFANCY For reasons not yet well understood (McCall & Carriger 1993), the magnitude of the correlation between infant measures of habituation (i.e. 2 to 8 months) and childhood measures of intelligence (i.e. 1 to 12 years) is temporally stable or even increasing (Cardon & Fulker 1991, DiLalla et al 1990), rather than decreasing over time. In contrast, relative stability after infancy is rather well described on the basis of quasi-simplex assumptions (Humphreys & Davey 1988, Molenaar et al 1991). Thus, adjacent time points in ontogeny tend to be more highly correlated than more distant time points. In addition, stability coefficients computed over identical lapses of time show a considerable increase in magnitude from childhood to adolescence into middle adulthood and early old age (Gold et al 1995, Hertzog & Schaie 1986, Humphreys & Davey 1988). For instance, Humphreys and Davey (1988) reported a continuous increase in one-year stability coefficients of general intelligence, with a value of .76 between the ages of four and five, and a value of .90 for the ages of eight and nine. With respect to later ages, Hertzog and Schaie (1986) found that seven-year stability coefficients for a general ability composite ranged from .89 to .96 in samples with mean ages between 25 and 67 years at first test. These are extraordinarily high levels of interindividual long-term stability.

Lifespan Changes in Heritability

A detailed coverage of behavior genetics and its role in the study of developmental pathologies (Rutter 1997) is beyond the scope of this article. Instead, the following synopsis is restricted to broad estimates of heritability in normal samples. To avoid misunderstandings, we emphasize that heritability coefficients refer to interindividual differences and therefore do not provide direct information about mechanisms of genetic expression. Specifically, the degree of heritability does not speak to the level (plasticity, malleability) of developmental outcomes (expression) that is available to all members of the population (PB Baltes 1998, PB Baltes et al 1998, Fox et al 1996).

Similar to lifespan changes in stability, heritability of interindividual differences increases from about 40% to 50% during childhood and adolescence to about 80% in early and middle adulthood (Carmelli et al 1995, McGue et al 1993, Saudino et al 1994). In contrast, shared environmental influences on interindividual differences generally do not persist beyond the period of common rearing (McGue et al 1993). The observed lifespan increase in the heritability of interindividual differences in intelligence is consistent with the notion that adolescents and adults have more of a chance to actively select environments that match their genes than infants and children do (Scarr & McCartney 1983). With respect to late-life heritability, recent data from the Swedish Adoption Twin Study of Aging (SATSA) suggest that heritability of interindividual differences in general intelligence may drop to values around 60% in old age (McClearn et al 1997).

Structural Changes in Intellectual Abilities: The Differentiation/Dedifferentiation Hypothesis

A major issue in lifespan intelligence is the question of structure and development-associated changes in structure. The best-known model involves a change in the structure of intellectual abilities toward differentiation in early life followed in late adulthood by the reverse process of dedifferentiation. According to the differentiation/dedifferentiation hypothesis, the amount of positive covariation among intellectual abilities, or the prominence of the general factor of intelligence (Carroll 1993, Reinert 1970), is inversely related to general (common) conditions of performance such as age or ability level. In part, this hypothesis is based on the assumption that low levels of intellectual functioning reflect limitations imposed by a set of common (system-general) biological (Spearman 1927) and/or environmental constraints. When applied to lifespan intellectual development, the differentiation/dedifferentiation hypothesis predicts that the prominence of the general factor decreases during childhood as a function of brain maturation and domain-specific knowledge acquisition, remains relatively stable throughout adolescence, adulthood, and early old age, but increases again late in life when system-general constraints such as biological brain aging regain importance.

Because of methodological difficulties in testing this hypothesis (Nesselroade & Thompson 1995), the relevant evidence is not conclusive, but generally seems to support this conjecture (Babcock et al 1997, PB Baltes & Lindenberger 1997, Deary et al 1996). For instance, recent findings suggest that ability intercorrelations both between and within fluid-mechanic and normative-pragmatic domains are of much higher magnitude in old age than the corresponding ability intercorrelations during middle and early adulthood (PB Baltes & Lindenberger 1997, Lindenberger & Baltes 1997). In addition, the covariance dedifferentiation observed in very old age appears to transcend the cognitive domain, affecting sensory functioning (e.g. vision and hearing) and sensorimotor functioning (e.g. balance/gait) as well (PB Baltes & Lindenberger 1997). One likely possibility for the high degree of ability homogeneity (dedifferentiation) in old age is the common causes of brain aging that affect all cognitive functions similarly.

CONCLUSIONS

During the recent decade, we have witnessed rigorous and varied efforts to understand human development from a lifespan point of view. One major goal of this chapter was to examine the degree of convergence between several levels of theoretical and empirical analysis.

We conclude that the work on lifespan development conducted at different levels of analysis evinces much convergence, and this represents theoretical progress in LP. In developing and refining its multi-level framework, LP has benefited much from transdisciplinary dialogue, especially with modern developmental biologists but also with cultural psychologists. Biologists, for instance, have led the way in moving research away from unilinear, unifunctional, and deterministic models of ontogenesis to a theoretical framework that highlights the contextual, adaptive, probabilistic, and self-organizational dynamic aspects of ontogenesis (Lerner 1998a, Magnusson 1996, Thelen & Smith 1998). In a similar vein, cultural psychologists and development-oriented social scientists (e.g. Cole 1996, Durham 1991, Elder 1998, Mayer 1990, Valsiner & Lawrence 1997) have succeeded equally in demonstrating not only that human ontogenesis is strongly conditioned by culture, but that the architecture of human development is essentially incomplete, not only for reasons of biological incompleteness but also regarding the culturally engineered pathways and possible endpoints (PB Baltes 1997).

The future of lifespan developmental theory will depend significantly on the extent to which the metatheoretical and empirical perspectives it has advanced turn out to be useful not only in the conduct of developmental research, but also in demonstrating the usefulness of the lifespan approach for other psychological specialties such as clinical (MM Baltes et al 1995, Smith et al 1994, Staudinger et al 1995), social (MM Baltes & Carstensen 1998, Carstensen 1995), personality (Heckhausen & Schulz 1995, Lachman & James 1997), and applied psychology (Abraham & Hansson 1995; Sterns & Dorsett 1994). In fact, these intersections of the lifespan approach with other psychological specialties need to be identified and nurtured. In the long run, it is these interconnections that will be the final testing ground of what lifespan theory and research has to offer to psychology, as a science and as a profession.

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