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On the Dynamics Between Growth and Decline in the Aging of Intelligence and Memory

P. B. BALTES and R. KLEGL

The view of aging and old age predominantly held in Western societies is one of general decline in capacity and efficiency. Older persons are judged to be less efficient, less adaptive, and less intelligent than younger adults. In addition to scientific evidence such as that collected in opinion surveys (e.g., [22]), the view of aging as decline is also evident in cultural products of art [28], as well as in everyday communications in the mass media. The image of old age as a period of decline seems deeply embedded in the social fabric of society.

Counterexamples to this view of aging as decline are considered exceptions to the rule. Individuals undoubtedly exist who perform extraordinary mental and physical feats in old age. Aside from well-known artists such as Pablo Casals, or the pianists Vladimir Horowitz and Arthur Rubinstein, consider the 75-year-old who has run the 42-km marathon in about 3 h 15 min, a time not easily reached by most young adults. Exceptions from aging as universal and inevitable decline, although they do not alter our general view, are important to note because they serve to challenge the boundaries of the “normal” and suggest the value of re-examining the limits of reality. Indeed, the search for the limits and plasticity of aging is the essence of our own research approach. In the area of intelligence, for instance, we are interested in understanding the conditions and range of reserve capacity or plasticity that older individuals hold in intelligence and cognitive functioning.

The view of aging as decline, or decline view, also characterized the beginning of psychological research on aging. During the last decade or so, however, the situation has changed. One much-debated question in the psychology of aging has become whether psychological aging is indeed solely a phenomenon of gradual, cumulative, and inevitable decline. Here, this debate will be illustrated in one research area—the study of intelligence and memory.

What is the scientific evidence on the aging of intelligence and memory? Recent decades have witnessed a number of new findings that challenge the stereotype of general and universal decline [5, 7, 9, 29, 31, 47]. Four lines of research are particularly relevant:

1. On the nature of aging of each of the several abilities that constitute the provinces of intelligence
2. On interindividual variability and cultural change in intellectual aging
3. On the plasticity (reserve capacity) of intellectual functioning in old age
4. On maximum limits of intellectual functioning

Together, these lines of research have opened a new window on the aging of intelligence and related cognitive functions.

**Different Intellectual Abilities Age Differently**

Most research on intelligence in adulthood and old age has employed standardized psychometric tests of intelligence. Such intelligence tests are based on a multiability structural conception of intelligence. Intelligence is not seen as a single ability; rather, it is conceived of as a system of multiple abilities. To view intelligence as a system of clusters of mental abilities permits the possibility that different abilities can age differently, in the same manner as different organs of the human body show different rates of aging [14, 20, 43].

In fact, the possibility that distinct intellectual abilities age differently is part of a major psychometric theory of intelligence developed by Cattell and Horn [12, 26, 27]. The central feature of the Cattell-Horn theory of intelligence relevant to considerations of aging is the distinction between two large clusters of intellectual abilities, fluid intelligence and crystallized intelligence. Fluid intelligence deals with the “content-free” basic processes of information processing and reasoning; another shorthand description of it would be that it represents the basic architecture or the basic “mechanics” of intellectual functioning. In order to minimize the role played by cultural content, fluid intelligence is assessed by efficiency of problem-solving with material that is novel or overlearned. Crystallized intelligence, on the other hand, refers to a cluster of subabilities that deal with content- and knowledge-based elaboration of reasoning. Crystallized intelligence, or the “pragmatics” of intelligence, is typically measured by tasks involving language, interpersonal communication, social intelligence, and cultural knowledge. Professional expertise and wisdom are exemplars of crystallized intelligence [16, 17].

What about the life-span developmental fate of fluid and crystallized intelligence, the mechanics and the pragmatics of intelligence? The theory postulates that fluid and crystallized intelligence show rather different trajectories of aging (Fig. 1). The initial course up to early adulthood is identical: both ability clusters show an upward trend. Beginning in middle adulthood, their aging differs markedly. Fluid intelligence is expected to exhibit a fairly early and regular aging loss. Crystallized intelligence, by contrast, is expected to continue growth during adulthood and show stability into old age.

It is now argued that age functions can best be identified when tested at “limits” of performance or reserve capacity: performing tasks under conditions of stress, of a high degree difficulty, or demanding extensive practice (expertise) (Fig. 2). In psychology, testing-the-limits – similar but not identical to stress testing in medicine – may become the chosen method of identifying aging changes both in the basic sci-
Dynamics Between Growth and Decline in the Aging of Intelligence and Memory

Fig. 1. Postulated developmental trajectories of fluid and crystallized intelligence. (After [12, 26])

Fig. 2. Testing-the-limits and the aging of the mechanics vs. the pragmatics of intelligence. Age changes affect functioning within the normal range less than at the limits. (After [7])

ence laboratory and in clinical practice [2, 7, 29, 46]. This topic is discussed in more detail later in this paper.

Why should fluid and crystallized intelligence differ so dramatically in their life-span developmental course? According to the theory, fluid intelligence reflects primarily the biological integrity of neurophysiological functioning and brain status. Because these foundations of fluid intelligence are susceptible to biological aging and neurological trauma over the course of life, fluid intelligence is predicted to decline with age, beginning in early adulthood. Crystallized intelligence, by contrast, is largely the manifestation of accumulated experience and cultural learning. As experience and learning continue throughout the life span, crystallized intelligence is expected to show an increase into late adulthood.

The Cattell-Horn theory, then, with its differing courses of aging for fluid and crystallized intelligence, is one of the first examples of the idea that intellectual ag-
ing is not synonymous with a general loss of functioning. Different ability clusters of intelligence do indeed age differently; there is both growth and decline during adulthood and old age. Empirical research supports the theory [27, 36]. Whereas most individuals show losses in measurements of fluid intelligence beginning around age 30–40, many individuals equally maintain their level of functioning in crystallized-type measurements, such as on a test of language knowledge, up to age 70.

Cultural Change and Interindividual Variability in Aging

The next line of research involves the study of cultural change and interindividual variability. This research has produced two other findings which demonstrate that the aging of intelligence does not follow a fixed course of continual and universal decline. The findings are a substantial degree of variation in the aging of intelligence (a) between persons and (b) between generations or birth cohorts.

The finding of cultural or historical variation in intelligence was possible because of the development of new research designs better suited to capture age development in a changing society. Whereas traditional research used simple age-comparative designs such as the cross-sectional or longitudinal method, since the late 1960s new methods have been developed that incorporate historical variations into these designs [4, 32, 39]. In part, this development of more complex aging designs occurred because simple cross-sectional and longitudinal studies did not produce the same outcomes. For decades, cross-sectional results had confirmed the expected pattern of loss of intellectual performance with age, beginning in early adulthood around age 30. The emerging longitudinal follow-up data did not show the same decline pattern: instead, in longitudinal studies, individuals up to age 60 or so exhibited little change in intellectual functioning.

One of the major reasons for discrepancy between cross-sectional and longitudinal studies is the existence of historical, cultural change. For these reasons the desired methodology is one in which age and generational or so-called birth cohort membership can be varied simultaneously. This is achieved by the application of so-called sequential strategies which consist of successions of cross-sectional and/or longitudinal studies as shown in Fig. 3.

Using such sequential strategies, Schaie and his colleagues began in 1956 what is now perhaps the classic study on adult and old-age development of intelligence; a study that has revolutionized our conceptions of the aging of intelligence. The study began with 500 subjects and has been continuously expanded at 7-year intervals, involving, as of 1984, a 28-year follow-up of more than 2000 subjects measured repeatedly on a large battery of intelligence tests [40, 41]. Control groups measured at longer intervals are also included (Fig. 4).

Two findings of Schaie’s research program are highlighted here: the results on (a) interindividual variability and (b) historical change.

Interindividual Variability. A first major finding in Schaie’s research is that of sizeable variability in the overall course of intellectual aging between individuals. Consider, for example, the onset of aging loss as illustrated in Fig. 5. Depending upon
CONVENTIONAL METHODS

SEQUENTIAL STRATEGIES

Fig. 3. Cohort-sequential strategies. (After [4, 39])

Fig. 4. Sequential strategy of Schaie's study of adult and old-age intelligence [41]

Fig. 5. Substantial individual differences in the course of intellectual aging from age 60 to 80. (After [5])
conditions of health, work context, and similar factors, aging decline can begin for different persons during the fourth, fifth, sixth, seventh, or even eighth decade of life. In current cohorts of fairly healthy American adults, aging loss in intelligence tests does not start before about age 55 for most individuals. However, the data still suggest that if individuals live long enough, aging decline in intellectual functioning is likely to begin at some point, however late [25, 42].

Another statistic offers further information on the relatively low average aging decline. Schaie [41] has shown that average aging decline in his subjects from age 60 to 80 is only about two-thirds of a standard deviation. This implies that about one-third of 70-year-olds perform above the mean of young adults in intelligence tests. In other words, there is a sizeable number of elderly persons who function at high levels even when compared with the young adult.

Historical Change. The data of Schaie's work [41] also show that performance on intelligence tests does not only change with age, but also with history. Cohort or historical differences between age levels can be as large as longitudinal aging changes within the same cohort. Consider, for example, the findings for one age group, say 53-year-olds, measured at different historical moments (1956, 1963, 1970, 1977, etc.) on five major intelligence abilities. For these 53-year-olds, the five different mental abilities show different patterns of historical change as shown in Fig. 6. Three show positive historical change, one is cohort-invariant, the fifth evinces negative change with historical time.

Because mental abilities change differently over historical time, such cohort effects support further the notion that intellectual aging is not solely a phenomenon of decline. Cohort effects of the magnitude reported in research on adult intelligence are novel to psychologists and perhaps also to neurologists. In our view, aside from the possibility of historical changes in the genome of the population, three clusters of environmental influences are primarily involved as origins of cohort effects and associated variability in the aging of intelligence: cultural changes in education, health, and work. Successive generations, for example, exhibit on the average more formal education and other forms of education-related experiences, such as those

Fig. 6. Historical change: simplified trends representing the average performance of 53-year-olds from different birth cohorts, as estimated by Schaie [41], based on time-lag comparisons
associated with the introduction of television. Many other facets of everyday life show sociocultural change that may be related to level and rate of intellectual functioning. At present, however, it is not yet possible to specify which of the factors are responsible for the cohort changes observed in intellectual aging.

Cognitive Intervention Research on Plasticity in Old Age

The results presented thus far describe what, in one Western cultural context and at a few historical moments, the aging of psychometrically measured intelligence looks like. The central finding is great variability and openness in level and course, between abilities as well as between individuals and historical cohorts. The aging of intelligence is not a rigidly fixed phenomenon that can be captured by simple age designs. No single cohort-specific or ability-specific study tells the final story on the aging of intelligence [4, 35, 38, 39].

Does variability between individuals have a counterpart in plasticity within one individual? The inquiry into variability of intellectual performance within the same person, i.e., plasticity or reserve capacity, has been the direction of our own recent research [10, 29]. We ask whether the variability in level of intellectual performance obtained in descriptive cohort and age comparisons can be simulated as plasticity in single individuals.

Psychological Evidence

One of our central resulting research questions is the following: Is it possible to elevate the level of intellectual performance of elderly individuals by an amount comparable to the one reported either as aging loss or as the difference between same-age persons from different cohorts? To resolve this issue we provide older individuals with added learning experience and practice in intellectual functioning.

Training of Intelligence Test Performance. Meanwhile, some ten cognitive training studies with a total of about 1000 older persons have been completed in our laboratories, in the United States at the Pennsylvania State University (with Sherry L. Willis) and at the Max Planck Institute for Human Development and Education in Berlin (with Freya Dittmann-Kohli). Each of the studies extended over a period of about 1 year [8, 10, 47]. Study participants are between 60 and 80 years of age and above average in health and education. We estimate that our participants, both country and city dwellers, represent perhaps 50%–75% of the 60- to 80-year-olds living in rural Pennsylvania and in Berlin.

In most studies, the training program consists of five to ten training sessions distributed over 1–2 months. Cognitive training focuses on that cluster of intelligence that according to theory and data is sensitive to aging loss, i.e., fluid intelligence. During training, reasoning problems similar to those contained in tests of fluid intelligence are explained, solutions are practiced, and corrective feedback is given.

The results of these various practice and learning studies are highly consistent. As is illustrated in Fig. 7 taken from Baltes et al. [8], older individuals benefit markedly from exposure to cognitive activity. In tests similar to the training focus, per-
performance gain is about one standard deviation: an amount rather similar to the aging loss reported in descriptive longitudinal research on this age range [41]. In addition, the training gain is maintained at all occasions studied following the practice sessions, i.e., up to 6 months following the intervention. The evidence for transfer from the abilities trained to other clusters of intelligence, however, is moderate. As might be expected, transfer to training is restricted of tests of intelligence tapping the same ability as that trained.

More refined analyses of test performances also show that trained older adults not only increase their average level of test performance, but are also more accurate (i.e., show fewer errors) and are able to solve more difficult problems than before the training program. Another important finding is that the large majority of participants in our research seem to profit from practice and training. Participants are classified into subgroups by, e.g., subjective health status, age, level of education, initial level of test performance or IQ, but these subgroups do not differ substantially in amount of training gain.

Training of Memory. During the last year we have extended our research on intellectual plasticity and reserve capacity to the area of memory [30]. Our training focus is on memory tasks (such as the well-known digit span) that require subjects to repeat strings of digits or words. Without training, typical subjects are able to repeat four to eight digits or a similar number of words in the correct order (3-1-5-0-8, etc., house-car-family-telephone, etc.).

Using theories of cognitive psychology and memory [13, 18], we have developed training modules that permit subjects to achieve record-like performances. These training programs extend over 30–50 individual sessions. Thus far, we have worked with 15 healthy elderly people in the age range 67–78. In terms of IQ, these subjects are above average. However, they were not selected because they are particularly gifted in memory functioning. In the course of the training programs we engineer an expert memory system that involves the acquisition and combination of three com-
ponents: working memory, a declarative knowledge system about digits, and a mnemonic strategy (Method of Loci) of encoding and retrieving [30].

As with our research on training psychometric intelligence, in this research on reserve capacity of memory our elderly subjects also prove capable of demonstrating remarkable gains in performance. After 30 sessions of memory training, all elderly subjects can repeat – under self-paced conditions of about 20-s presentation intervals between words – at least 30 words in the correct order after one presentation of the list of words (Fig. 8). As to digit strings, all elderly persons studied so far are able to repeat – again under self-paced presentation rates of about 20-s intervals – strings of digits as long as 40 after they have been presented only once. Our best elderly person can repeat a string of 120 digits with a presentation rate of 8-s;

**Fig. 8.** Research on reserve capacity: performance of four elderly subjects in word span and digit span. (From [45])
on the surface, at least, an amazing performance for a 70-year-old. Note that presenting a string of 120 digits at an 8-s presentation rate takes 16 min.

These memory task performances by elderly people are of such magnitude that they can be classified as approaching the performances of expert mnemonists [18]. Thus the findings suggest that, as in the area of psychometric intelligence, many elderly people have a reserve capacity of memory functioning extending far beyond our everyday and scientific conceptions of what the aging of memory is like.

One missing piece of the puzzle is whether the everyday world of many older persons is indeed one that generates intellectual atrophy, due to lack of experiences and demands conducive to high intellectual performance. Based on casual observation and sociological analyses of role changes following retirement, this seems a reasonable assumption. A major tenet of the sociology of old age is that aging brings with it a loss of social role and involvement, but careful, direct observations of intelligence-related behaviors of older persons are not yet available. An exception, perhaps, is the observational work of Margret M. Baltes from the Free University of Berlin [1, 3]. She has shown that the social ecology of nursing homes is one that steers elderly residents toward dependent rather than independent, self-sufficient behavior. Such research on nursing home residents, however, may not tell the ecological story of fairly healthy older individuals such as the ones participating in the research on intelligence reported here.

To prevent possible misinterpretation of our research on plasticity and reserve capacity, some cautionary comments are necessary. The results do not imply the following three conclusions. First, that older adults profit more from intelligence or memory training than young adults. As there are no good age-comparative studies on training gain, no definite knowledge about this question and the extent of reserve capacity or plasticity existing in different age groups is available. Second, that the training programs raised the level of intelligence or memory as a whole to the level shown in younger adulthood. In fact, the gain was demonstrated only for those abilities or components that were part of the training activity.

The third possible misinterpretation would be that all aging individuals display the plasticity reported here. We do not know the subject generality of our findings. While we do believe that most elderly individuals up to age 80 or so are capable of major training benefits as reported here, we need to re-emphasize that our samples are clearly biased towards the healthy elderly and most likely do not include persons who suffer from brain-related diseases such as senile dementia of the Alzheimer type. Certainly there are aging-related disease groups for which we would not expect the magnitude of plasticity demonstrated by our elderly subjects.

**Brain-Physiological Evidence**

So far we have summarized evidence for plasticity on the level of behavioral assessment of intelligence and memory. Since fall 1984, we have been collaborating with the Max Planck Institute for Neurological Research at Cologne in examining whether the psychological plasticity of intellectual functioning observed in many elderly people has a correlate or counterpart in physiological brain functioning [24]. This collaboration involves the use of positron emission tomography (PET). PET