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first published in:
Human memory and cognitive capabilities : mechanisms and performances; symposium in memoriam Hermann Ebbinghaus -1885 - Berlin Humboldt University - 1985- / ed. by F. Klix and H. Hagendorf. - Amsterdam [u.a.] : North Holland, 1986, S. 395-407, ISBN 0-444-70069-2

TESTING-THE-LIMITS, EXPERTISE, AND MEMORY IN ADULTHOOD AND OLD AGE

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This research has three interrelated foci: (i) engineering and testing a cognitive model of expert memory, (ii) the study of intellectual reserve capacity and (iii) the use of a testing-the-limits methodology to magnify and delineate age differences in limits of reserve capacity. The assumption is that age differences are magnified if studied at high levels of expertise or task difficulty. Results from age-comparative point training studies in expert memory are reported. Both young and elderly subjects reached high levels of skilled memory, confirming the model. However, despite this sizeable reserve capacity, when compared to IQ-equivalent young adults, superior elderly showed decline in upper limits of function.

INTRODUCTION

The present series of intensive single-subject studies offers preliminary evidence. They represent a combination of pilot projects aimed at establishing the basis for future research on expertise and memory in a life-span developmental framework (Kliegl and Baltes (1984)). However, the preliminary findings are such that they warrant some tentative conclusions. Two general strategies associated with cognitive psychology, on the one hand, and developmental research methodology on the other, guide our approach.

Our central cognitive-psychological orientiation is to synthesize or engineer a cognitive skill in a theory-guided manner in order to: (1) better specify the components underlying the skill, and (2) have control over the construction of the expertise and over performance at high levels. We argue for a strategy in which expertise in memory is constructed in the laboratory following an *a priori* specified multi-component model of memory functioning. Rather than decomposing naturally acquired skills involved in memory and cognitive processing (Hunt (1978), Sternberg (1977)), we propose to construct systems and levels of performance not usually naturally available in subjects' repertoires. This permits control over the components involved. When subjects have been taught to be experts according to a model, their expert-level performances are assumed to only be possible when, and if, they apply the strategies or processes built into their system as a function of the acquisition process.

The key argument of our developmental-methodological orientiation is that age differences are more easily identified at performance limits, that is, in test conditions that require subjects to go beyond their normal range of functioning. In the normal range of functioning, we contend that too many alternative interpretations cloud the picture of age comparison, such as pre-experimental practice differences between age groups, the use of substitutive or compensatory processes, or the operation of task-extrinsic motivational factors. As a consequence, evidence on the nature and explanatory origins of developmental change is often rather uncertain or contradictory. Therefore, we propose to search for developmental and aging functions under conditions of high difficulty and at high, expert-like levels of performance (Baltes, Dittmann-Kohle, and Dixon (1984), Charness (1981), Kliegl and Baltes (1984), Salthouse and Somberg (1982), Salthouse, in press). At limits of performance, we expect age differences to be magnified and the relative importance of task or ability-extraneous performance factors to be reduced. In the ideal case, then, non-overlapping age distributions would result at limits of performance. The methodological strategy to be used for such a study of high levels of performance is called testing-the-limits (Baltes et al. (1984), Baltes, M. and Kindermann (1985), Kliegl and Baltes (1984), Schmidt (1971), Wiedl (1984)).[2]

In our present research program on memory development and memory in old age we have combined both strategies. Theory-guided cognitive synthesis or cognitive engineering is used to construct and teach expert-like memory functioning using a model that specifies the components and processes involved in an _a priori_ manner (Kliegl, Smith, Heckhausen, and Baltes (1985)). After expert levels are acquired, subjects are tested at higher and higher levels of performance, thus approximating their limits or maximum reserve capacity. Using this dual-pronged approach, we expect insights both into the range of reserve capacity as well as into the processes characteristic of development and aging.

THE ENGINEERING OF EXPERT MEMORY

General Approach. Experts are defined as persons whose performance on some criterion task is far superior to that of normal persons (Charness (1981), Chi, Glaser, and Rees (1982), Glaser (1984), Hoyer (1985)). For the most part in extant research on expertise, experts are identified from real-life settings (e.g., chess, typing, physics) and studied with regard to the cognitive systems and processes associated with expert functioning. This has been true also for most work on expert memory (Ericsson (1985)).

Our own approach is different. We join the smaller group of researchers who focus on the controlled acquisition of complex cognitive expertise under laboratory conditions (e.g., Anderson (1981), Chase and Ericsson (1982), Salthouse and Somberg (1982)). This approach is more tedious as it requires extensive longitudinal, single-subject type work associated with the acquisition of an expertise. At the same time, we believe that this approach permits better specification of the factors and processes involved in an expertise.

We believe also that most individuals (and not only particularly gifted ones) are quite capable of acquiring high levels of expertise in select domains. There is nothing magical about many forms of cognitive performances considered to be expertise. In many instances the necessary ingredients are but three. First, there must be at least one explicit model of a cognitive system that accounts for and simulates the acquisition of the requisite knowledge and mental processes associated with the expertise involved. Second, a given individual must have available the normal set of cognitive resources characteristic of most adults. Third, she/he must be sufficiently motivated to engage in extensive practice. Certainly, individuals will differ in the "final" level of expertise achieved. Most, however, will be successful in reaching high levels of performance.

Expert Memory in Digit and Word Span. To date, we have chosen to focus on memory for strings of digits and words. Much influenced by the work of Chase and Ericsson (1982), we have constructed several explicit models and training programs for the acquisition of skilled performance on digit and word span tasks. Each of these models is expected to be effective in principle, although when applied, it is likely that subjects will differ in their rate and level of acquisition as a function of the particular method trained.

Table 1 presents a taxonomy of basic cognitive processes and declarative knowledge potentially involved in digit and word span. The heuristic taxonomy presented in Table 1 organizes skilled memory into three provinces: working memory, long-term memory encoding/retrieval strategies, and domains of knowledge. Components from these provinces can be combined in various ways to engineer expert-like performances in memory-span tasks.

Table 1
Taxonomy and Examples of Cognitive Components Potentially Involved in Digit Memory Tasks

Working Memory	LTM Encoding/ Retrieval Strategies	Domains of Knowledge
- central executive[1,2,3]	- Method of Loci[2,3]	- historical knowledge[2]
	- Figure Alphabet[3]	
- articulatory loop[1]	- chaining[1]	- concrete nouns[3]
	- chunking[1,2,3]	
- visuo-spatial scrach pad	- ...	- running times[1]
		- Berlin landmarks[2,3]
- auditory loop		
- finger loop		- phone numbers
- ...		- ...

Note

[1]Primary components used by Chase and Ericsson's (1982) subjects.

[2]Components used in the History-Dates Model.

[3]Components used in the Digit-Noun Model.

Table 2 illustrates two concrete implementations: (1) the History-Dates model, and (2) the Digit-Noun model. The two models are identical in the use of the Method of Loci (see below). They differ mainly in the type of permanent knowledge they require. In the History-Dates model, knowledge about historical dates is acquired in terms of the last triplet of each historical unit (1945 = 945, 1492 = 492). One thousand historical dates are necessary to have a full account of all possible variations of random digit sequences (000 - 999). In the Digit-Noun model, digit doublets are recoded into concrete nouns (e.g., 40 = RoSe) using a digit-consonant scheme known as Figure-Alphabet. One hundred words are necessary to have a full account of all digit doublets possible (00, 01 ... 99). Thus, the two models differ in the kind and size of the knowledge necessary to generate all possible combinations of random digit sequences. Table 2 illustrates how a random string of digits can be recoded into a random sequence of historical events or concrete nouns, respectively.

In both models, sequences of recoded digit triplets (i.e., historical events) or of recoded digit doublets (i.e., nouns) are committed to long-term memory by means of the mnemonic technique known as the Method of Loci (cf. Bower (1970), Spence (1984), Volkmann (1929), Yates (1966)). Our subjects work with a list of 30 or 40 locations representing landmarks in Berlin (West) as indicated in the middle column of Table 2. During encoding subjects form funny, bizarre or dynamic images or thoughts linking the to-be-remembered items (i.e., historical dates or concrete nouns) with the Berlin locations. Because landmarks are mentally visited in an invariant sequence during encoding, they can serve as retrieval cues when the subject "re-visits" them at time of recall. The Berlin landmarks, their sequence and the Method of Loci procedure thus constitute a highly overlearned part of permanent knowledge. Which particular historical date or concrete noun must be remembered at which location is, of course, trial-dependent.

The sequential chunking of digits into historical events (or concrete nouns) and the formation of images or thought associations between these to-be-remembered items and their corresponding landmark does not put a heavy burden on working-memory subsystems such as rehearsal loop or visuospatial scratch-pad (cf. Baddeley (1983)). Only central executive functions which serve to integrate relevant knowledge elements are required. Therefore, in the present models, expertise in memory span is not constituted by increasing short-term or working memory (as in the research of Reisberg, Rappaport, and O'Shaughnessy (1984)), but by invoking long-term memory encoding processes and permanent knowledge during encoding (as proposed by Chase

Table 2
Illustration of History-Dates and Digit-Noun Models

Knowledge System (History-Dates Model)	Encoding/ Retrieval Sequence	Knowledge System (Digit-Noun Model)
Digits to be coded:		Digits to be coded:
492789945 ... 618		407800 ... 86
Historical Dates	Method of Loci	Digit-Noun Pairs
	30 Berlin landmarks	
(1) 492=1492=Columbus	(1) Botanical Garden	(1) 40=R S=RoSe
(2) 789=1789=French Rev	(2) Museum	(2) 78=C F=CoFfee
(3) 945=1945=End WW II	(3) Church	(3) 00=S S=SuSy
.	.	.
.	.	.
.	.	.
(30) 618=1618=Beginning 30-Year War	(30) Fountain	(30) 86=F SH=FiSH

Note

In each model the Method of Loci is combined with one of two knowledge systems. In the History-Dates model, using digit triplets, 1000 dates (000-999) would be necessary to encode all digit triplets. The Digit-Noun model, using digit doublets, provides a match to all random sequences based on 100 nouns.

and Ericsson (1982)). Once the memory expertise has been acquired, capacity limitations in working memory functioning (e.g., in the capacity of the central executive to integrate STM and LTM processes) can be probed, for example, by manipulating the rate at which items to-be-remembered are presented (e.g., reducing presentation rates). Such a probe technique illustrates one theory-guided implementation of our testing-the-limits strategy.

Do the Models Work? Preliminary data suggest that the two models outlined here do operate as predicted. So far in our training program all adult subjects have been quite capable of acquiring the Method of Loci and using this mnemonic strategy to remember long series of words. Some subjects have reached a level at which they are able to combine this method with their acquired knowledge system about digits to remember long digit sequences. As expected, however, subjects differ in the rate and level of expert memory achieved. At present, not all subjects in our laboratory have been exposed to all components of the system. To begin, our training program required participation in only 30 sessions. For some subjects this was not sufficient to achieve a sufficient level of performance in the Method of Loci and the requisite digit knowledge. There is no indication, however, that the majority of subjects in the program would not achieve some level of expertise if they continued to participate in additional sessions.

Figures 1 and 2 are presented as illustrations of the performance of subjects who acquired high performance levels relatively quickly. They represent data from two young subjects with

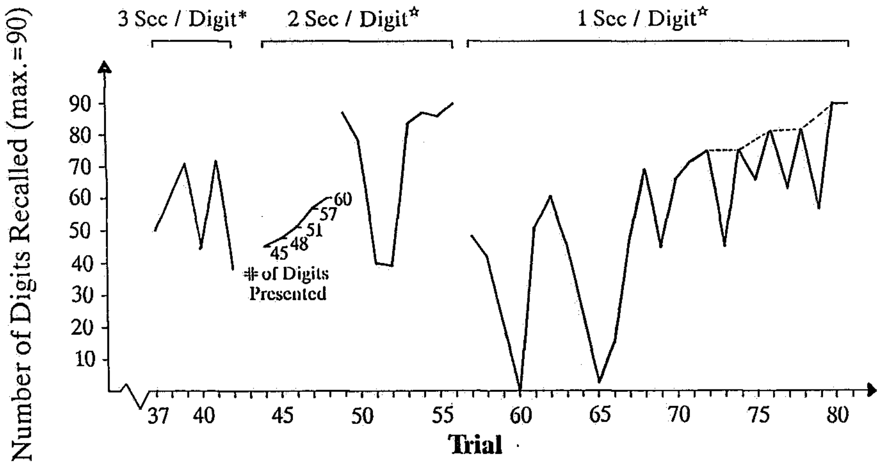

Figure 1
Subjects Sp's acquisition of skilled digit memory using the History-Dates model: Number of digits, recalled in correct positions as a function of experimental trial and presentation rate per digit.

above average Hamburg-Wechsler-IQ (Kliegl, Smith, Heckhausen, and Baltes (1985)). At present, these subjects have achieved (after some 40-60 sessions) levels of performance approximating more and more those attained by so-called expert mnemonists (Ericsson (1985)) and by the two subjects of Chase and Ericsson (1982). The best performances known to us of Chase and Ericsson's two subjects were digit spans of 82 and 68. Note, however, that these levels were achieved following 264 and 286 practice sessions, respectively. The best performances on digit span tasks reported prior to the Chase and Ericsson work were around 20 digits and were typically displayed by "mental calculators" or professional mnemonists.

One of our subjects (SP) (see Figure 1) uses the History-Dates model with 30 locations (maximum possible span = 90 digits). Currently, this 23-year old subject is able to recall strings of 90 digits at presentation rates of one to two seconds per

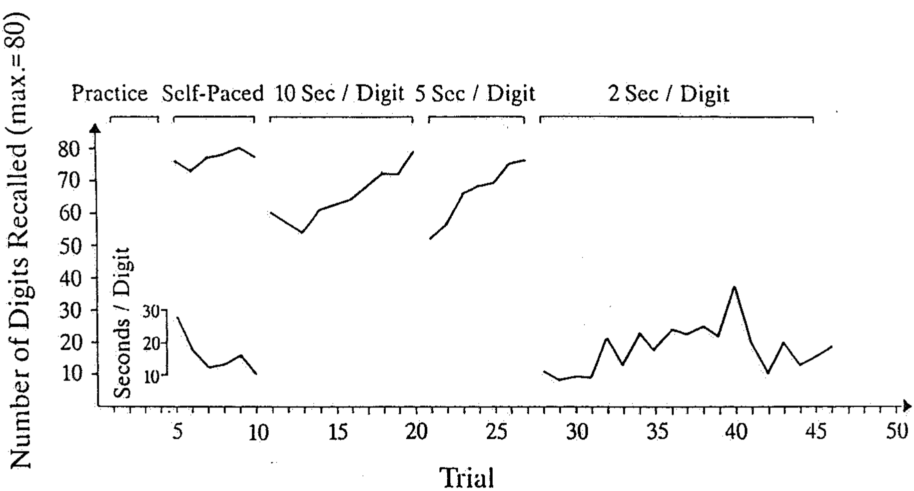

Figure 2
Subject BB's acquisition of skilled digit memory using the Digit-Noun model: Number of digits recalled in correct position as a function of experimental trial and presentation rate per digit.

digit. Recall is restricted, however, to digit sequences consistent with his knowledge of historical dates (currently, SP has 100 historical dates available). The other young subject (BB) (Figure 2), age 19, use the Digit-Noun model with 40 locations, permitting him to store and retrieve potentially any random sequence of 80 digits (40 locations x 2 digits). This subject is currently able to recall 80 digits at a presentation rate of five seconds. Performance at a 3-second interval is currently being practiced.

The cognitive engineering of memory expertise works also with older subjects. Currently, ten elderly persons (ages 67-78 years) are participating in a long-term intensive training program. To date, all have been taught to use the Method of Loci with 40 locations to remember strings of nouns. After 30 sessions, eight of these ten elderly persons were able to use the Method of Loci under self-paced conditions to recall consistently close to 40 words in correct serial position. The remaining two elderly subjects--while not fulfilling the 90% criterion--are able to recall correctly between 80% and 90%. Four elderly have progressed from self-paced to faster presentation rates. Three of them are able to recall 40-word lists at criterion (36 in correct position of 40) when nouns are presented in fixed intervals of 20 seconds. One of our older subjects, the best, is able to recall 30 of 40 words that were presented at a rate of four seconds per word.

Can older adults also be trained to use the History-Dates model to encode and retrieve strings of digits? Of four elderly persons who, so far, have participated in a training program based on the History-Dates model, all were able to recall digit sequences of 60 (i.e., using 20 locations) under self-paced conditions. The following is the best performance we have so far observed in our laboratory: One elderly woman (age 69)--after 13 practice trials of the History-Dates model and 38 sessions of memory training--is able to recall strings of 120 digits (40 locations x 30 triplets) presented once at a fixed rate of eight seconds per digit. Note that presentation of such a long digit string takes 16 minutes.

In sum, these finding indicate that the models of expert memory for digit- and word-span work, in principle, for all participating subjects. All subjects have the reserve capacity to reach fairly high levels of expertise. Note again, that the expertise acquired is not based on an unknown system of functioning. Rather, level of expertise is based, at least primarily, on the components specified _a priori_ by the investigators. Unless the subjects use the model engineered, they would not be able to produce expert-level functioning.

We have also designed investigative strategies by which the components involved in the models are (a) measured separately, and (b) systematically removed from the system. For example, presenting subjects with digit sequences incompatible with their knowledge system (History-Dates model) and requiring that the sequence of locations constituting the map for the Method of Loci be scrambled are two techniques we have used to investigate the susceptibility of the expert system to componential deconstruction. Although these additional findings on deconstructing the system are not part of this report, it is fair to state that the results are consistent with the interpretation offered here. When components are removed, the expertise--as predicted--breaks down.

AGE DIFFERENCES

The second main research strategy that characterizes our general approach is the use of expertise as a tool to implement a testing-the-limits strategy directed toward the magnification of developmental differences. As has been mentioned already, same-aged subjects differ markedly in their rate and level of acquisition. We also expect age differences to be enlarged and to be robust (perhaps even irreversible) if studied at experts levels and near limits of performance.

At present, our age-comparative design is incomplete, in part because the intensity of research forced us to work with small numbers of participants. As our general expectation for the tasks involved is one of fairly robust aging loss at expert levels of functioning, we decided to proceed in our pilot program of research in a manner that favored falsification of the expectation: (1) We selected only well-functioning and a larger number of older adults (N = 10) than younger adults, thereby increasing the likelihood that some older adult may outperform the young; (2) We selected among the young not only above-average (N = 2) but also below-average subjects (N = 3). The selection criterion was estimated Hamburg-Wechsler IQ. Our older superior and younger superior adults have an IQ higher than 115. The below average young adults have an IQ at or below 100.

Figure 3 presents relevant data for the Method of Loci (40 locations, nouns as stimuli) from all subjects who had appropriate data (superior old: N = 10; below average young: N = 3; superior young: N = 1). The outcome is clear. Note first that the subjects did not differ markedly at baseline. Second, all subjects demonstrate a substantial amount of reserve capacity. For example, under self-paced conditions and following 30 sessions of training (about one hour each) the lowest performance in a test trial is displayed by one older subject. This elderly person, however, was still able to recall (immediately following presentation) 33 of 40 words in the correct order.

Third, as testing conditions for recall were made more and more diffictult by shortening the presentation rate (from self-paced to fixed rates of 20, 15, 10, 4, and 2 seconds), individual differences incrased. Individual differences--not very pronounced at baseline--are magnified at expert levels.

Fourth, none of the ten superior older adults reached the level of performance displayed by their young superior counterpart. The above-average young adult was able to repeat a list of 40 words correctly up to the fast presentation rate of 4 seconds per word.

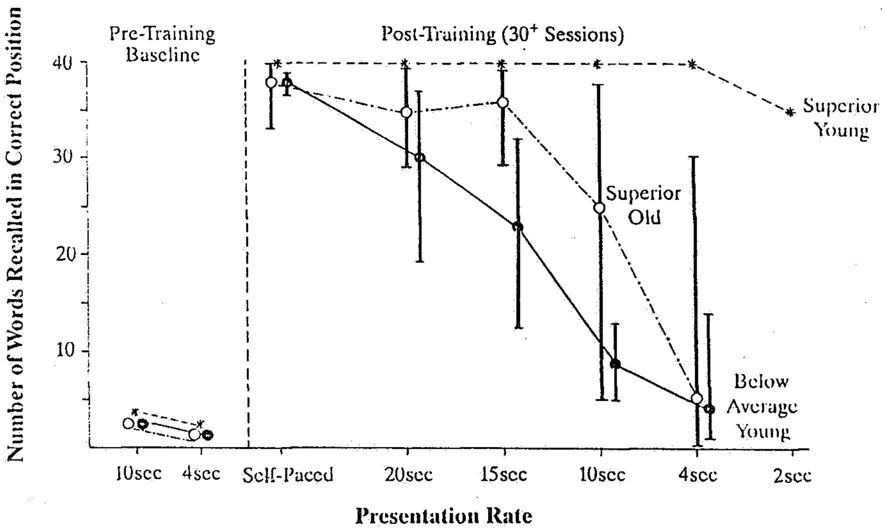

Figure 3
Expertise in Method of Loci: Mean and range of recall for 40 words in three subject groups of young and old adults.

Fifth, the performance of above-average older adults is at about the same average level as that for below-average young adults. The largest share of the existing difference between well-functioning elderly and below-average young subjects in favor of the elderly is produced by one elderly who functions at a higher level than her age peers.

Sixth, the digit span performance of this best older adult, however, does not yet approach the speed of processing (8 sec. vs. 4 sec.) displayed by our one superior young adult (SP, see Figure 1). The second young above-average subject (BB) working with us using the Digit-Noun condition is also working at a faster presentation rate than our best elderly person (see Figure 2). Thus, at limits the two young IQ-equivalent subjects outperform all elderly persons studied so far.

Can the robust age difference suggested by the comparison between superior elderly and the two young adults (who are comparable in IQ to the elderly) be specified further? At present, we are conducting further experiments to identify the origin(s) of this age difference at limits of performance. What strikes us most is that the origin(s) may reside primarily in the formation of thoughts leading to images as required by the Method of Loci mnemonic. All subjects appear to be able to accuracy. What seems to distinguish subjects is their ability to generate and maintain "good" images or thoughts for encoding and retrieval. Good images in the Method of Loci are assumed to be unique, vivid, and dynamic. Superior older adults like below-average young adults seem to have more difficulty in generating such images at a consistently fast rate. However, further work is required to substantiate this hypothesis.

DISCUSSION AND SUMMARY

The research program described here examines two questions: (1) the effectiveness of a cognitive engineering approach for the acquisition of skilled (expert) memory for digit and word span; and (2) the usefulness of a testing-the-limits approach for the specification and magnification of subject differences particularly as these relate to aging.

Two findings, preliminary as they are, are of particular significance. First, it has been demonstrated that cognitive engineering toward expert memory is possible for many adults including the elderly. The cognitive apparatus of most healthy adult and elderly individuals seems to hold the necessary reserve capacity. Second, expertise-like models can be used for the magnification of individual differences in general and of age differences specificly.The usefulness of expertise models for the study of subject differences is further enhanced when combined with a testing-the-limits approach, and especially when that approach is aimed at testing performance in conditions that require all the reserves available to a given subject (e.g., stress testing). In the present study, this was accomplished by increasing presentation rate. Thus, the research technique has successfully magnified individual differences--differences not apparent at baseline.

Aside from the study of additional subjects and extending the practice offered, the next steps in our research program are two-fold. First, we would like to specify more precisely the processual nature of the components responsible for the obtained aging effect. In general, since our engineering of maximum functioning is model- or theory-guided, we expect to be in a better position, than is true for past gerontological work, to determine for each individual the particular cognitive components that lead to expertise but also to breakdowns in performance.

Second, by further use of the testing-the-limits methodology we expect to gain insight not only into aspects of reserve capacity (plasticity) but also into the constraints on development. Life-span research on intellectual development over the last decade has opened our vista for cognitive plasticity in the sense of not yet realized (unknown) possibilities for adult growth in intelligence (Baltes (1984), Dixon and Baltes (1985), Labouvie-Vief (1982)). The present work on limits--while at the same time continuing the search for the unknown potential--offers the necessary counterpart: A systematic search for constraints (Keil (1981)). Plasticity of and constraint on development are the cornerstones for a comprehensive view of what individuals can do, may be able to do, and may not be able to do as they develop and age (Baltes et al. (1984), Lerner (1984), Salthouse and Somberg (1982)).Of course, knowledge about the limiting boundaries is always incomplete. There most likely are no definite fixed limits in the absolute sense. New conditions may emerge that add to the resources available. However, aside from futuristic thinking, we tend to believe that information about peak performance is better information about plasticity and constraints than assuming everything is possible or impossible in principle.

FOOTNOTES

[1]The research program on Expertise and Life-span Development of Memory is co-directed by Paul B. Baltes and Reinhold Kliegl. Additional scientists in the research program are Jutta Heckhausen (research fellow) and Jacqui Smith (research fellow). We thank especially Roger A. Dixon, Daniel P. Keating, Timothy A. Salthouse, and Alexander von Eye for helpful discussions. For assistence in data collection and data analysis we would like to acknowledge W. Assmann, S. Lempert, E. Pichler, A. Rentz, and W. Scholtysik.

[2]We do not assume that processes of aging are always changes toward decline. On the contrary, similar to Cattell and Horn's model of fluid vs. crystallized intelligence, we distinguish between two domains evincing distinct life-span trajectories: the mechanics and the pragmatics of intelligence(Baltes et al. (1984)). The content-free mechanics are assumed to show decline with aging at limits of functioning; select aspects of the content-rich pragmatics, contrariwise, are expected to possibly show advances into old age in healthy elderly. The present research on expert memory deals more with the mechanics than the pragmatics. Thus, we expect decline with aging near limits of functioning.

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