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# 15

## Process Dissociations in Cognitive Aging

*R. Kliegl, U. Mayr, and R.T. Krampe*

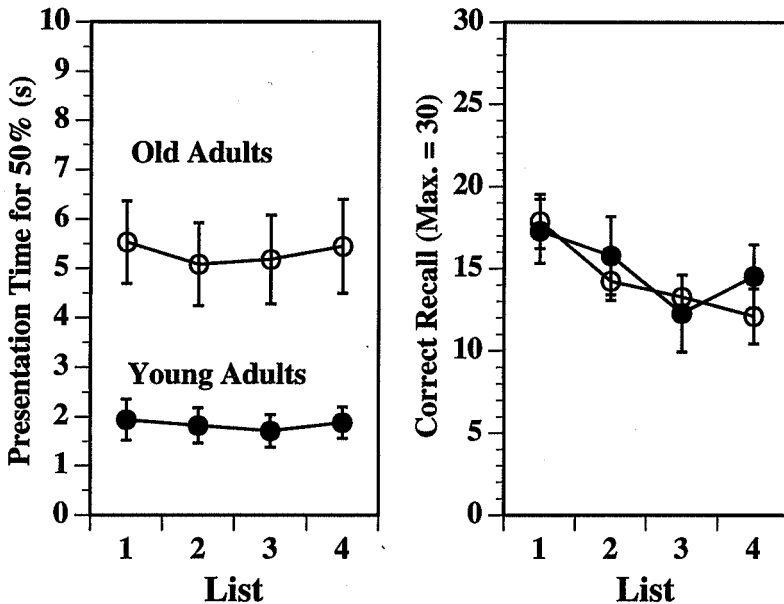
One undisputed finding of cognitive aging research is that the two main clusters of intellectual abilities, fluid and crystallized abilities, exhibit differential age-related trends. Healthy older adults perform less well than young adults on almost any task that requires fast responses or taps the fluid or mechanical aspects of intelligence; they show much less of a decline, if any at all, in tasks requiring the access of their crystallized knowledge (Baltes, 1987; Horn, 1970). These age-differential trends are the prototype of what we will refer to as a process dissociation. We will show how process dissociations can be established within the domain of fluid intelligence that pass more stringent tests than is customary in experimental research on cognitive aging.

### TASK SPECIFICITY AND GENERAL SLOWING

Is the age-related difference between fluid and crystallized intelligence the only process dissociation in cognitive aging? From an experimental perspective the answer to this question is undoubtedly "no." A scanning of journals devoted to the study of aging will reveal an abundance of task-specific or process-specific age differences, for example, related to findings such as age differences in the distinctiveness of encoding or in retrieval strategies in memory tasks; Salthouse (1991) provides extensive tables of such explanations culled from the *Journal of Gerontology* and *Psychology and Aging*. A problem with interpreting these findings as evidence for process dissociation is that they usually derive from significant ordinal interactions in experimental designs; they often seem to reflect the fact that the age difference increases with the difficulty of the experimental condition. It is well known that such interactions make strong assumptions about the scale of the dependent variable and can

be rendered insignificant by a suitable transformation of the scale (Loftus, 1978). This problem would have left experimentally oriented researchers in cognitive aging undisturbed had it not been for people such as Cerella (1985, 1990) and Salthouse (1985) who—put simply—pointed out that if we look at performance *ratios* of old and young adults rather than performance *differences* there is very little variance attributable to process-specific effects. In particular, for tasks using response latency as the dependent variable most of the age differences attributed to process-specific deficits can be explained by assuming that older adults process information at a slower rate than young adults. From this perspective, then, the argument is that within the domain of fluid intelligence (to which most speeded tasks belong) there is little evidence for process dissociation if we compare young and old adults with respect to proportional instead of difference scores.

The research we have been carrying out tried to establish process dissociations of cognitive functioning within the domain of fluid intelligence taking into account the conservative criterion of proportional rather than absolute age differences. In other words, we subscribed to a new null hypothesis: We only interpret an age difference as process-specific if the old-young performance ratio is larger relative to a control condition. First we looked for evidence for process dissociation within the memory domain. We used cognitive intervention to demonstrate that there is plasticity and learning potential in old adults' episodic memory for word lists. At the same time we hoped to elicit larger and more robust age-effects than is typical in the field of aging because we expected that training would bring participants closer to their limits of performance and that age-differential limits in basic cognitive functioning would be most pronounced when participants are induced to mobilize as many as possible of the cognitive resources they still have available (e. g., Kliegl, Smith, & Baltes, 1989; Baltes & Kliegl, 1992). The performance ratios of these training studies were based on accuracy measures. Therefore, they were not directly comparable to meta-analytic summaries based on response latency tasks which suggested a task-invariant slowing ratio. Our training program, however, contained information that could be used for a more adequate comparison. In order to provide old adults with as good a learning environment as possible, practice sessions were tailored to each individual's ability. This way, we hoped to avoid boredom due to lack of challenge, as well as frustration due to conditions beyond the reach of the current ability. One method we used to this end was to vary presentation time such that all participants were about equal in performance (see Figure 15.1, from Kliegl & Lindenberger, 1993). For example, we decided on a performance criterion of 15 out of 30 words. If, in a given list, a participant met this criterion, the presenta-



**FIGURE 15.1** Illustration of criterion-referenced testing across four lists of an experimental session. Age differences are reflected in the presentation times needed to maintain a 50% level of correct recall (from Kliegl & Lindenberger, 1993).

tion time was shortened in the following list. If he or she did not meet the criterion, more presentation time was available for the next list. On average, old adults were allotted more presentation time per word than young adults but there was very little difference between age groups in the number of words recalled.

Figure 15.1 suggests that old adults can have as accurate a memory as young adults if they are given more time to generate the memory traces. This result raises an interesting question of compensation. Can older adults compensate their decline in memory accuracy by taking more time to complete the task? If one thinks of time as a resource, an idea forcefully argued by Salthouse (1985), the question is: How much more time do healthy old adults need to achieve the same level of accuracy as young? Two times as much, or four times as much time? Does this factor depend on the type of task? In earlier meta-analytic summaries of cognitive aging research (integrating several hundred published studies) Cerella (1990) came up with a remarkable constant slowing factor between 1.5 and 1.8 for tasks in which response latency was used as the

dependent measure. This factor was determined by regressing the mean response latencies of old adults on those for corresponding experimental conditions of young adults (Brinley, 1965). From these analyses Cerella concluded that, in general, task- or process-specific explanations are not necessary to account for the age differences. Rather the age-related decline observed for these tasks was compatible with a task-independent, general decline in information processing speed or cognitive slowing. Goodness of fit was improved for curvilinear models allowing the age differences to increase for more difficult tasks (e.g., Cerella, 1990; Myerson, Hale, Wagstaff, Poon, & Smith, 1990). Note that the authors of the original publications on which these meta-analyses were based had invariably interpreted the typical ordinal age  $\times$  condition interactions as evidence for task- or process-specific age deficits.

In our own research (Kliegl & Lindenberger, 1993; Kliegl, Mayr, & Krampe, 1994; Thompson & Kliegl, 1991) we had determined the demand of presentation time for equal accuracy in four memory experiments with a total of 10 different conditions (see Figure 15.2). To check whether proportional age differences in the time demand for equal accuracy varied between tasks we plotted criterion-referenced presentation times of old adults against those of young adults of corresponding conditions. The regression line represents the time demand young and old adults need for equal accuracy. For example, the triangle in the lower left gives the time that was needed by the age groups when they had to recall 12 of 16 words; the triangle in the upper right gives the values for 16 out of 16 words in the same experiment; each point in this figure represents the mean time demand of old and of young adults in the same experimental condition. The pattern we observed was quite regular although the experiments differed in a number of aspects such as the length of the lists (the range was from 16 to 30 words to be recalled), the criterion (time demand was determined for values between 50% and 100% on every other list), and the difficulty of the nouns to be recalled. Common to all experiments was that memory traces had been generated on the basis of an instructed mnemonic technique.

The slope of the regression of old on young adults' criterion-referenced presentation times was 3.8; the associated  $R^2$  was .92. Note that the slope of 3.8 suggests that the effect of age on episodic memory is about *twice* as large as one would expect from cognitive aging research using tasks that put little demands on memory such as choice reaction and visual search tasks. Thus, our cognitive intervention and testing-the-limits strategy obviously was successful in revealing a domain of cognitive processing that was slowed much more pronouncedly than summaries of cognitive-aging research based on response latency tasks had indicated. Nevertheless, within the domain of episodic memory the effects of

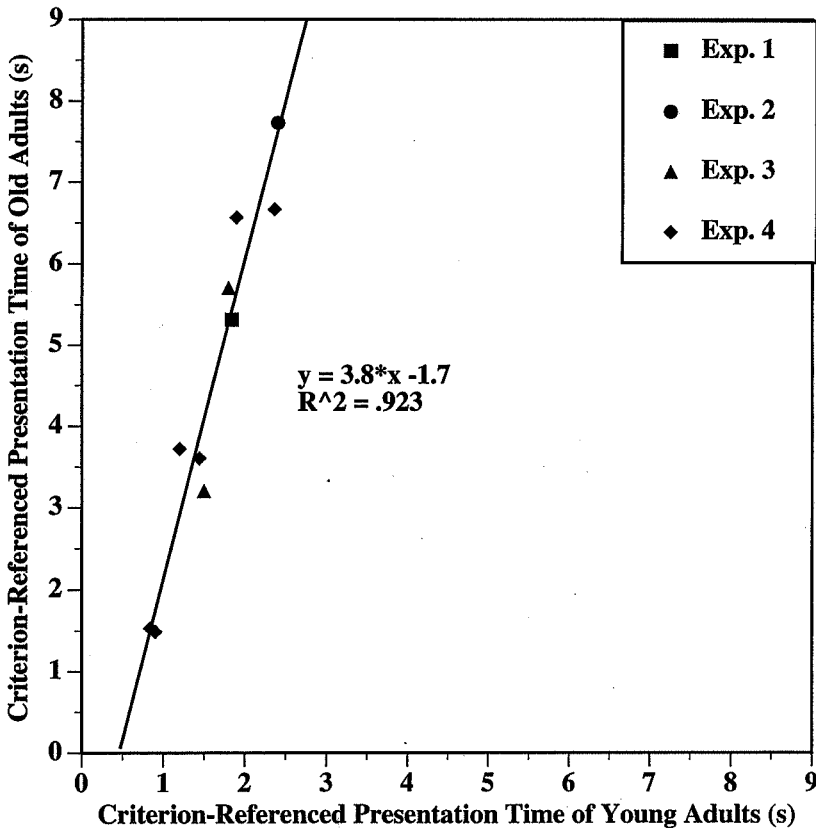


FIGURE 15.2 Meta-analysis of age differences in criterion-referenced presentation times (iso-accuracy young-old function) based on four experiments (Kliegl & Lindenberger, 1993; Baltes & Kliegl, 1992, second training phase; Thompson & Kliegl, 1991; Kliegl, Mayr, & Krampe, 1994).

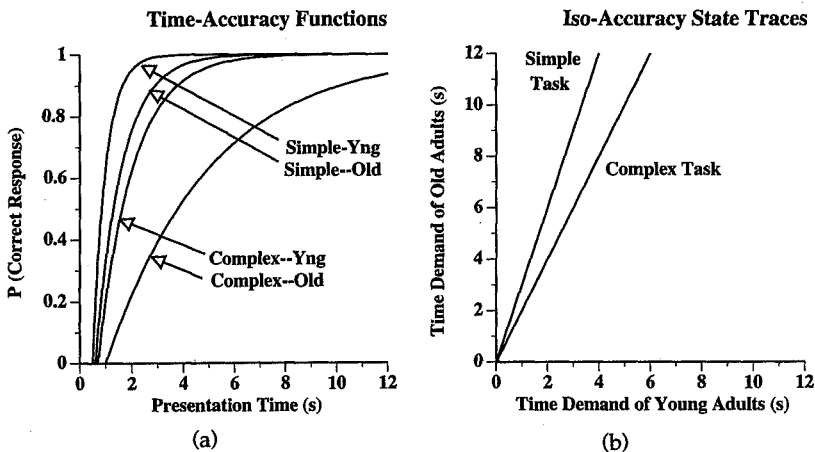
age under a wide variety of experimental manipulations appeared to be characterized by the same proportional factor. Finally, we were also able to show that individual differences in criterion-referenced presentation times are highly predictive of traditional accuracy scores (Kliegl, in press).

#### TIME-ACCURACY FUNCTIONS AND ISO-ACCURACY STATE TRACES

Based on the set of memory results we started to determine presentation times required for different levels of accuracy within the same person.

The idea was to map out for each individual the function relating presentation time to performance accuracy covering the functional range between chance and close to perfect performance. This is a bit more complicated than standard research because for each person a different segment of presentation times is involved. An adaptive testing procedure automatically sampled—for each subject in each condition—presentation times from the entire time-sensitive segment of the time-accuracy function without confronting subjects with non-informative presentation times, that is times that are either too long or too short. This yielded enough information to estimate the relation between presentation time and accuracy for any level of accuracy between chance and perfect performance using a negatively accelerated exponential function as a reference (Kliegl, Mayr, & Krampe, 1994; see Figure 15.3a for examples).

Thinking about time as a resource determining accuracy is somewhat different from the way psychologists have been thinking about effects of time. In an analysis-of-variance design, presentation time is an independent variable; tests of effects of age or task focus on (vertical) differences in accuracy. Our approach, which one may call a psychophysics approach to cognitive processes, in contrast, focuses on the (horizontal) differences in presentation time at a given level of accuracy. This is analogous to the determination of perceptual thresholds in psychophysics.



**FIGURE 15.3** (a) Illustration of time-accuracy functions for a simple and a complex task for groups of young and old adults. Curves are based on the means of two parameters (x-intercept, slope) estimated for each person in each condition. (b) Iso-accuracy state traces for young and old adults in terms of time demands for simple and complex tasks (adjusted for age- and task-specific times of process initialization). For details see Kliegl, Mayr, and Krampe (1994).

For example, one decreases or increases the amount of energy to find out how many quanta of light one needs for a specified probability of seeing a stimulus. In this sense, we determine the amount of presentation time needed for cognitive rather than perceptual "thresholds." This kind of reasoning can be applied to a wide variety of cognitive tasks including tasks for which traditionally response latency has been used as the primary dependent variable, such as search and reasoning tasks.

Once the functions are determined for individual persons, allowing for interindividual differences in intercept with the x-axis and in the slope of the function, group curves can be derived by computing the function based on the group means of free parameters. In a dissociation experiment one needs at least two experimental conditions (a simple and a complex one for which the dissociation is to be demonstrated) and two (age) groups yielding a total of four time-accuracy functions. From these four time-accuracy functions two iso-accuracy state-traces can be derived by plotting for a given condition the time needed by old adults over the time needed by young adults for all accuracies; of course analytical solutions are also available. As shown in Figure 15.3b, for exponential time-accuracy functions, state-traces are linear; the slopes of these iso-accuracy curves are equal to the ratios of slopes of corresponding time-accuracy functions. Different proportional slowing factors characterize the two conditions if the slopes for the two conditions are significantly different from each other, that is, if there is a significant age  $\times$  condition interaction for log-values of the slopes of individual time-accuracy functions (see Kliegl et al., 1994).

### THREE APPLICATIONS

#### Reading and Remembering Words

We attempted to establish the pattern of results illustrated in Figure 15.3 in a series of ongoing experiments. I will describe three results. In a first contrast, we asked whether the large age-related proportional slowing in memory tasks (see Figure 15.2) was due to the memory component or due to using criterion-referenced presentation times rather than response latencies (Kliegl et al., 1994). Therefore, we converted a condition that traditionally had been measured with response latency (i. e., scanning a short list of words for a target) to the criterion-referenced assessment procedure. Moreover, this condition can be construed as a component process of traditional list recall. Concretely, list memory tasks have two components: First, one has to read word pairs. Then, one has to generate a mental image for them. The first component puts little demand on cognitive processing (at least as long as the words are simple) but the second



component requires fantasy and creativity and the mobilization and retrieval of knowledge. The results we obtained followed the pattern displayed in Figure 15.3. Thus, the different proportional slowing factor was due not to the different method, but most likely reflected additional processing demands related to the generation of mental images.

### **Low and High Demands on Coordinating Information in Working Memory**

In a second contrast we examined how old and young adults responded to an increase in the processing demands of working memory. We expected that the slowing factor would be much larger when demands on working memory are high than when they are low. The two task conditions were variants of a figural transformation task (Mayr & Kliegl, 1993). The experimental manipulation implemented a distinction between sequential and coordinative complexity. Sequential complexity denotes the systematic checking of items where each check can be carried out independently of previous processing steps such as standard visual search for a target. This condition puts very small demands on working memory. Coordinative complexity refers to conditions in which there is a need to coordinate information in working memory in order to arrive at a correct solution. For example, in one condition participants had to discount that a figural array had been rotated while they were searching for a target. We suspect that older adults lose information which has to be kept "alive" in working memory (such as a mentally rotated spatial array) more frequently than young adults. This loss in turn triggers a need to repeat processing steps. All of this should translate into a much larger demand on presentation time for equal accuracy. The results were again compatible with state-trace slopes of about 3 and 2, respectively (see Figure 15.3). Thus, in the simple search task old adults needed roughly twice as much time as young adults; when information had to be coordinated in working memory, they needed more than three times the amount of presentation time as young adults (Kliegl et al., 1994; Mayr & Kliegl, 1993).

### **Proactive Interference: Acquiring New vs. Revising Old Knowledge**

In the third contrast, in ongoing research, we test the hypothesis that adult age differences in updating of memory are more severe than the learning of new material (Kliegl, Krampe, & Mayr, 1993). The difference between updating (or revising) memory and the acquisition of new material is realized by an experimental manipulation of proactive interference (i. e., the negative consequences of earlier on later learning). The

phenomenon of proactive interference has been known since Müller and Pilzecker's (1900) work. It is still an intriguing question in the field of aging because it has been very difficult to demonstrate age difference in proactive interference although virtually any theoretical account postulated that old adults should be more affected by such an experimental manipulation. Up to the nineties the typical textbook conclusion was that there apparently are no age differences in proactive interference.

Proactive interference depends on the similarity of the material to be remembered. The low proactive interference, easy condition was our standard memory task. Subjects are presented pairs consisting of a location and a noun. They must generate mental images linking them. During recall, they are asked which noun went with this location. Critical for this experiment is that in each list a new set of nouns had to be memorized. In contrast, in the difficult condition, the high proactive interference condition, the same nouns had to be remembered in each list but they were always re-assigned to different locations. The task here then is one where it is critical to revise information available. Obviously, it is more difficult to revise or update one's memory than to acquire new information. In terms of time-accuracy functions we expected that the curve for the updating or revision condition would lie to the right of the new-learning condition. More presentation time should be required to achieve an equivalent level of accuracy. Initial results of this study suggest that we were able to demonstrate a different, perhaps even a quite different type of age difference: For the learning of new words old adults were able to reach 100% accuracy—of course, they needed more time for each accuracy than young adults. The asymptotic maximum accuracy, however, was much lower under conditions of high proactive interference. In contrast, young adults were able to achieve maximum accuracy in both conditions. These data suggest that age differences in proactive interference can *not* be compensated by extending presentation time. This result poses serious problems for "simple" models of age-related slowing which do not allow for this possibility. The mechanisms responsible for this apparent lack of compensatory power of presentation time are not clear but might be related to the strong age-related decline in the integration of contextual information (Kliegl & Lindenberger, 1993).

## SUMMARY

An important task of cognitive aging research is to delineate domains of functioning that are differentially affected by age. Ideally these domains should have a scope that extends beyond the specific task of a given experiment. Meta-analytic studies suggest that ordinal interactions in analysis of variance designs may identify too many process-specific

effects of age because they generally ignore differences in general task complexity between experimental conditions. We proposed an alternative approach for the isolation of proportional factors based on the determination of complete time-accuracy functions. The data suggest that at least three levels of process dissociation can be reliably identified in cognitive aging. These are fewer than traditional experimental research leads one to expect, but more than extant models of cognitive slowing claim.

### **Level 1: Fluid vs. Crystallized Abilities (Non-Lexical vs. Lexical Processes)**

There is little disagreement that fluid and crystallized abilities follow distinctly different age trends. This dissociation appears in the differential as well as in the experimental tradition of cognitive aging research. In experimental research small or no age differences are reported for organization and richness of knowledge as well as for the rate and amount of spreading activation in semantic networks (for a review see Light, 1991). The absence of age-differential slowing with respect to the time course of knowledge activation poses obvious problems for general models of cognitive slowing but is still subject to controversy (Laver & Burke, 1993; Lima, Hale, & Myerson, 1991). A dissociation based on time-accuracy functions would be desirable.

### **Level 2: Search Processes vs. Working Memory/Episodic Memory**

Within the fluid domain of functioning there is evidence that different proportional factors characterize the age differences associated with the demand on working memory. If later processing steps require mentally represented information of earlier ones, older adults show a deficit that cannot be explained by extant linear and curvilinear slowing models that were largely derived from age differences in visual search tasks. Within these two domains of tasks, however, a wide variety of different tasks appear to be characterized by the *same* proportional factor (see Mayr & Kliegl, 1993). A pattern of proportionate age differences statistically identical to the one just described was observed for a task contrast between episodic memory and scanning a short array of words. Interestingly, proportional slowing factors were statistically not different for figural search and word scanning tasks, neither were the proportional slowing factors for figural reasoning and episodic memory. The agreement in amount of proportional slowing for the simple tasks was expected, as both are variants of visual search. The fact that coordination in working memory and the generation of episodic memory traces led to a

similar proportional slowing factor may be due to chance but could also point to a common source of memory-related age differences. Corroborative evidence is also provided by Rabbitt (1993) who reported substantial age differences for memory tasks after statistical control of speed tasks.

### **Level 3: Revising Memory vs. Acquisition of New Material**

The third level of process dissociation suggests that there are experimental conditions in which healthy old adults apparently are not able to achieve the same level of accuracy even if given as much time as they want. In these conditions, there were limits to absolute accuracy presentation time would buy. Extant models of cognitive slowing cannot accommodate such results because they assume age invariance with respect to accuracy of performance. We want to point out that there may be instructions or other training programs under which this deficit in asymptotic accuracy might be overcome. It certainly is an issue that warrants further research because, if proven reliable, such results could provide powerful constraints for new models to be built.

The levels of dissociations presented here are a taxonomy of empirical observations; they can be thought of as "filters" for domain- rather than task-specific effects of cognitive aging. The danger associated with this approach is that some reliable task-specific age effects may be overlooked. The taxonomy does not rule out the possibility of encompassing models of cognitive aging but rather provides a platform for the construction of models that specify functional relations between the levels of process dissociation. For example, Mayr and Kliegl (1993) show how different proportional slowing factors emerge if one assumes age differences both in basic-level processing speed and susceptibility to losing information from working memory. Finally, the delineation of age-differentially affected domains of cognitive functioning proposed here easily transfers to other person characteristics, in particular to contrasts based on known or suspected pathologies. In this context, for select studies, the information gained about the processing dynamics generating condition-specific time-accuracy functions and iso-accuracy state traces may well outweigh the larger "costs" (in comparison to traditional measures) in terms of assessment time.

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