

The Berlin Aging Study

Aging from 70 to 100

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Limits and Potentials of Intellectual Functioning in Old Age

Ulman Lindenberger and Friedel M. Reischies

In the first-occasion Intensive Protocol of the Berlin Aging Study ($N = 516$), a psychometric battery of 14 cognitive tests was used to assess individual differences in five intellectual abilities: reasoning, memory, and perceptual speed from the mechanic (broad fluid) domain, and knowledge and fluency from the pragmatic (broad crystallized) domain. In addition, the Enhanced Cued Recall (ECR) test was administered in the context of a separate neuropsychological examination to identify dementia-specific cognitive impairments in cue utilization and learning potential. The overall pattern of results points to sizable and highly intercorrelated age-based losses in various aspects of presumably brain-related functioning, including sensory functions such as vision and hearing. Intellectual abilities had negative linear relations to age, with more pronounced age-based reductions in mechanic than pragmatic abilities. Ability intercorrelations formed a highly positive manifold, and did not follow the mechanic-pragmatic distinction. Gender differences were small in size, and did not interact with age. Indicators of sensory and sensorimotor functioning were strongly related to intellectual functioning, accounting for 59% of the total reliable variance in general intelligence. Even for knowledge, sociobiographical indicators were less closely linked to intellectual functioning than the sensory-sensorimotor variables, and accounted for 24% of the variance in general intelligence. With respect to potentials, results obtained with the ECR test demonstrate that the ability to learn from experience is preserved in normal cognitive aging across the entire age range studied, but severely impaired in individuals with dementia.

1 Introduction

Personal integrity is commonly associated with basic intellectual faculties such as the ability to reflect and remember. Conversely, the decline of these abilities is often linked to illness, need for care, and the disintegration of the self. Hence, the effects of biological aging on intelligence are perceived as particularly threatening. Medical and psychological research on this issue has led to ambiguous results, which strengthen and weaken these concerns. On the one hand, it is worrisome that, with increasing age, a rising proportion of the old and very old is afflicted by Alzheimer's disease and other severe brain disorders (Häfner, 1992; Hofman et al., 1991). On the other hand, the continued existence of learning ability in healthy older adults, the stability and/or increase of predominantly knowledge-based abilities, and the indisputable existence of mentally fit individuals among the very old give rise to optimism (Lindenberger & Baltes, 1994a).

In light of the ambiguity and scarcity of relevant data for the very old segment of the life-span, our primary goal in this contribution is to document and describe intellectual

abilities in old and very old age, such as their age gradients, intercorrelations, age-based differences in various aspects of variability, and their embeddedness in sociobiographical as well as aging-related biological systems of influence.¹

In addition, a related but secondary goal of the present study is to link the major findings emanating from this descriptive enterprise to central themes and concepts of life-span theory (P. B. Baltes, Lindenberger, & Staudinger, 1998) and cognitive aging research (Craik & Salthouse, 1992; Lindenberger & Baltes, 1994a). Typical examples of such themes and concepts include the two-component model of life-span cognition (P. B. Baltes, 1987, 1997; cf. Cattell, 1971; Horn, 1982), the dedifferentiation hypothesis of intellectual aging (P. B. Baltes, Cornelius, Spiro, Nesselroade, & Willis, 1980; Garrett, 1946; Lienert & Crott, 1964; Reinert, 1970), and the distinction between normal cognitive aging and aging with dementia (Buschke, Sliwinski, Kuslansky, & Lipton, 1995, 1997; Nebes, 1992).

We begin this chapter by presenting our general approach and the relevant measures (Section 2). Based on the psychometric battery of intellectual abilities, we then report the age gradients, intellectual-ability intercorrelations, and correlates of intellectual functioning for the total sample (Section 3). Subsequently, we report analyses attempting to separate cognitive aging without dementia from cognitive aging with dementia (Section 4). Finally, we point to the methodological shortcomings of the present data set, summarize the main findings, and discuss the relevance of the observed negative age differences for everyday intellectual functioning in old and very old age (Section 5).

2 Methods

2.1 General Design Features and Sample Description

The data presented in this article refer to all individuals who completed the 14-session Intensive Protocol of the first measurement occasion of BASE ($N = 516$, age range = 70–103 years, mean age = 84.9 years, $SD = 8.7$ years). The sample is stratified by age and gender, resulting in 43 men and 43 women in each of six different age brackets (70–74, 75–79, 80–84, 85–89, 90–94, 95+ years; cf. P. B. Baltes et al., Chapter 1 in this volume; Nuthmann & Wahl, 1996, 1997). Stratification has two interrelated main advantages over the necessarily skewed (e.g., age) and unbalanced (e.g., gender) distributions resulting from representative sampling schemes: (a) It produces equally reliable estimates of population parameters across all levels of the age variable and in both genders; (b) it greatly enhances the likelihood of detecting interactions of age and/or gender with other variables (cf. McClelland & Judd, 1993).

The analysis of sample selectivity has been a central part of the design and analysis of BASE (cf. P. B. Baltes et al., Chapter 1; Lindenberger et al., Chapter 2). With respect to mean-level selectivity, estimates based on repeated applications of the Pearson-Lawley formulae indicate that the Intensive Protocol sample (i.e., the target sample of this chapter, $N = 516$) has a positive selection bias in many domains of functioning such as somatic health, Activities of Daily Living, sensory-sensorimotor and intellectual functioning, social network size, and various personality dimensions such as openness to

¹ Some of the findings summarized in this chapter have been published before in English (P. B. Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1997) and German (P. B. Baltes & Lindenberger, 1995; Lindenberger & Baltes, 1995a; Reischies & Lindenberger, 1996).

Table 12.1. Internal consistencies, interrater or intercoder agreements, and factor loadings of the 14 cognitive tests

Ability	Name of test ^a	α^b	r^c	τ_c^d	β^e
Reasoning	Figural Analogies	.90	—	—	.76
	Letter Series	.86	—	—	.79
	Practical Problems	.84	—	—	.82
Memory	Paired Associates	.87	.99	.94	.72
	Activity Recall	.61	.91	.80	.82
	Memory for Text	.57	.96	.86	.66
Perceptual speed	Identical Pictures	.90	—	—	.89
	Digit Letter test	.96	1.00	1.00	.90
	Digit Symbol Substitution	—	1.00	.99	.92
Knowledge	Spot-a-Word	.92	—	—	.66
	Vocabulary	.82	.96	.85	.83
	Practical Knowledge	.82	.95	.84	.87
Fluency	Categories (Animals)	—	.99	.94	.87
	Word Beginnings (Letter "S")	—	.99	.94	.78

^aDetailed descriptions of the tests are provided in Lindenberger et al. (1993).

^bCronbach's alpha. Incorrect responses as well as performance on items that were not attempted were coded as zero.

^cIntercoder reliability (Pearson's r); not present for tests with computerized response entry.

^dIntercoder reliability (Kendall's Tau- c); not present for tests with computerized response entry.

^eFactor loadings (i.e., path coefficients) for a latent factor model with intercorrelated intellectual abilities (for details, see Lindenberger & Baltes, 1997).

experience. The magnitude of these selectivity effects was largest for general intelligence but never exceeded half a standard deviation. Generally, and with the exception of dementia prevalence, where the positive selection bias (e.g., the degree to which dementia prevalence was underestimated) was estimated to be largest in the very old segment of the population (i.e., age 95 and older), observed selectivity did not interact to a sizable degree with age or gender. More importantly, selectivity analyses did not provide any strong evidence in favor of a distortion of variances or covariances as a consequence of sample attrition. This suggests that the structural relations among variables, which figure prominently in this report, were influenced very little by sample selectivity.

2.2 Psychometric Battery of Cognitive Tests

The cognitive test battery comprised 14 tests measuring five intellectual abilities: (a) *perceptual speed* (measured by Digit Letter, Digit Symbol Substitution, and Identical Pictures); (b) *reasoning* (Figural Analogies, Letter Series, and Practical Problems); (c) *memory* (e.g., short-term acquisition and retrieval; Activity Recall, Memory for Text, and Paired Associates); (d) *knowledge* (Practical Knowledge, Spot-a-Word, and Vocabulary); (e) *fluency* (Animals, Letter "S"). A detailed description of the tests has been provided elsewhere (Lindenberger, Mayr, & Kliegl, 1993). The internal consistencies, interrater agreements, and confirmatory factor loadings of the tests for the present sample (i.e., $N = 516$) are reported in Table 12.1. The reliability estimates (i.e., internal

consistencies and/or interrater agreements) were satisfactory for all tests in the battery. In accordance with earlier analyses based on a subsample ($n = 156$) of the present data set (Lindenberger & Baltes, 1994b), the correlational structure of the cognitive battery was well described by a hierarchical factor model consisting of five first-order factors representing the five different intellectual abilities and a single second-order factor representing general intelligence (see Fig. 7.1 in Smith & Baltes, Chapter 7; for details, see Lindenberger & Baltes, 1997).

Construction of the battery was informed by the two-component model of intelligence (P. B. Baltes, 1987, 1997), which is closely related to the Cattell-Horn theory of fluid and crystallized intelligence (Gf-Gc theory; Cattell, 1971; Horn, 1982, 1989; for a comparison of the two approaches, see P. B. Baltes et al., 1998). Specifically, perceptual speed, reasoning, and memory represent the "mechanics" of cognition, whereas knowledge and fluency primarily represent the pragmatics of cognition, or individual differences in acquired, culturally relevant bodies of knowledge.

Cognitive testing was assisted by a Macintosh SE/30 equipped with a touch-sensitive screen. With respect to tests related to reasoning and knowledge, items were ordered by ascending order of difficulty, and testing was terminated when subjects made a certain number of *consecutive* failures (three in the case of Figural Analogies, Letter Series, Practical Problems, and Spot-a-Word, six in the case of Vocabulary). With the exception of the Digit Letter and the Digit Symbol Substitution tests, instructions were presented in large fonts on the computer screen. In case of the Digit Letter and the Digit Symbol, instructions were presented in large fonts on a piece of paper.

Testing took place at the residence of the subjects. Tests were administered in the following order: Digit Letter, Spot-a-Word, Memory for Text, Figural Analogies, Letter "S," Vocabulary, Practical Problems, Digit Symbol Substitution, Activity Recall, Identical Pictures, Paired Associates, Animals, Letter Series, and Practical Knowledge. In 81% of the cases, the entire test battery was carried out in a single session. In almost all remaining instances, testing was divided into two sessions. In that case, the first session ended with Activity Recall, the second session began with Identical Pictures, and all tests were administered in the original sequence. Persons who could not work on the computerized version of the battery because of very poor vision or blindness were administered a shortened auditory version of the battery.

Overall, 494 of the total of 7,224 attainable data points (i.e., 516 persons by 14 tests), or 7%, were missing from the psychometric battery data set. Unless stated differently, the data reported in this article refer to the persons-by-variables matrix after replacement of missing data through estimates based on linear regression. Missing data were estimated *within* each of the five intellectual abilities, that is, without the use of information based on tests of the remaining four intellectual abilities (for more information, see Lindenberger & Baltes, 1997).

2.3 Neuropsychological Assessment

The psychometric battery of intellectual-ability tests was complemented by a neuropsychological examination (for more information, cf. Reischies & Geiselman, 1994; Reischies & Lindenberger, 1996). In the following report, we focus on three measures: (a) the Enhanced Cued Recall test (ECR; Grober, Buschke, Crystal, Bank, & Dresner, 1988) to estimate interindividual differences in encoding specificity, which is as-

sumed to be selectively impaired in dementia (Buschke et al., 1995, 1997); (b) the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975); and (c) an index of brain atrophy based on a CT scan of the brain.

In the *Enhanced Cued Recall test*, 16 pictorially represented concrete items are repeatedly shown with and without category cues at both encoding and recall (for a full description of the procedures, see Grober et al., 1988). The present report focuses on cued recall after the first, second, and third learning trial. Both initial level and degree of improvement over consecutive trials are seen as indicators of effective cue utilization, and are assumed to reflect the specificity with which items are encoded during repeated presentation.

The *Mini Mental State Examination* is a standard multi-item checklist, and is often used as a screening device in epidemiological studies of dementia. The German translation followed Zaudig et al. (1991). For the analysis reported in this chapter, we used the short form of the MMSE (SMMS; cf. Klein et al., 1985).

The *brain atrophy index* was determined as part of the medical examination of BASE (Steinhagen-Thiessen & Borchelt, Chapter 5). A CT scan was performed at two different layers of the brain; both internal atrophy (e.g., ventricle size) and external atrophy (e.g., the distance between the brain and the skull) were assessed, and were subsequently rated by an experienced clinician on a four-point scale. The clinician was blind to all other characteristics of the participants including their age. The present score is based on the unit-weighted composite of the indices of inner and outer atrophy, which were moderately intercorrelated, $r = .54$. Primarily for organizational reasons, the CT scan was administered to only 254 of the 516 participants (mean age = 81.5 years, age range = 70–99 years, $SD = 7.7$). Of these 254, 143 were male, and 24 had received a clinical diagnosis of dementia. Additional procedural and descriptive information regarding this measure can be found elsewhere (Reischies, Rossius, & Felsenberg, 1997).

2.4 *Other Measures*

In addition to the psychometric test battery of intellectual abilities and the neuropsychological measures, a number of other constructs will be considered in this chapter. Most of these constructs refer to sensory-sensorimotor or sociocultural/biographical correlates of intellectual functioning, and allow us to position individual differences in intelligence among old and very old adults in relation to these two systems of influence. Detailed descriptions of these constructs are provided elsewhere (see Lindenberger & Baltes, 1997, as well as the original references provided below). In the following, we restrict ourselves to a brief definition of each variable.

Auditory acuity (i.e., hearing) was assessed in decibels, and refers to reverse-coded hearing thresholds in both ears for pure tones of eight different frequencies (i.e., 0.25, 0.50, 1.00, 2.00, 3.00, 4.00, 6.00, and 8.00 kHz; cf. Lindenberger & Baltes, 1997; Marsiske et al., Chapter 13).

Balance/gait was measured with two clinical assessments of balance and gait, the Romberg trial and the 360° turn (cf. Lindenberger & Baltes, 1997; Marsiske et al., Chapter 13).

Of the 516 participants, 109 (i.e., 21%) received a *clinical diagnosis of dementia* according to DSM-III-R (American Psychiatric Association, 1987) criteria (cf. Helmchen et al., Chapter 6; very mild to mild: $n = 37$; moderate: $n = 33$; severe: $n = 39$).

General somatic morbidity corresponds to the number of distinct clinically relevant diagnoses according to ICD-9 criteria; $M = 8.1$, $SD = 4.0$. A detailed description of somatic morbidity in BASE is provided by Steinhagen-Thiessen and Borchelt (Chapter 5).

Income represents the amount of net income in DM per month per capita on a five-point scale (1 = less than 1,000; 2 = 1,000–1,399; 3 = 1,400–1,799; 4 = 1,800–2,199; 5 = 2,200 and more; $M = 3.44$, $SD = 1.22$). Detailed information regarding the income distribution in this sample can be found elsewhere (cf. Mayer et al., Chapter 8).

Medication refers to the number of prescribed medications; $M = 3.6$, $SD = 2.7$ (for more details, see Steinhagen & Borchelt, Chapter 5; Linden et al., Chapter 16).

Social prestige is based on a standard rating scale of occupational prestige in Germany (cf. Mayer et al., Chapter 8). Ratings refer to the prestige of the participants' last occupation before retirement.

For *social class*, participants were arranged on a continuum of social stratification, ranging from lower class (7% of the sample), lower middle class (20%) to middle middle class (31%), upper middle class (30%), and higher middle class (11%; cf. Mayer et al., Chapter 8).

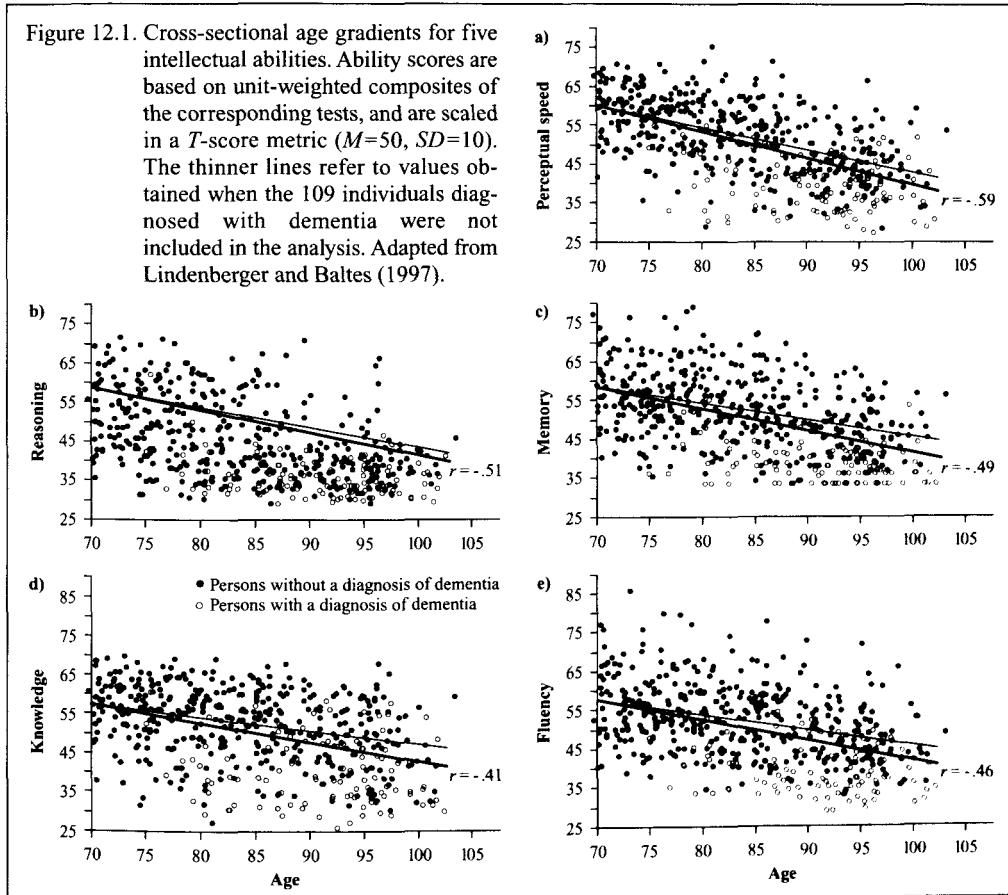
Visual acuity (i.e., vision) was measured in Snellen decimal units at two different distances using two different standard reading tables (cf. Lindenberger & Baltes, 1997; Marsiske et al., Chapter 13). Measurements were taken without and with the best optical correction (i.e., glasses) available to the subject. Analyses reported in this chapter are based on better values, which in most cases referred to corrected vision.

Years of education represents the number of years spent in formal educational settings. In addition to the number of years spent in elementary school and the different types of high school in Germany (Hauptschule, Realschule, Gymnasium), it also includes formal occupational (e.g., apprenticeships) and academic (e.g., university) training. On average, participants in this sample had 10.8 years of education ($SD = 2.3$).

3 Intellectual Abilities in Old and Very Old Age: Age Gradients, Structure, and Correlates

In this section, we report the age gradients, structure, and correlates in intellectual functioning as assessed by the psychometric battery of intellectual abilities. By default, analyses refer to the entire Intensive Protocol sample ($N = 516$), that is, they include individuals with a clinical diagnosis of dementia. In addition, we also mention results for the sample obtained after excluding individuals with a clinical diagnosis of dementia ($n = 407$, mean age = 83.3 years).

This section's focus on the full sample, rather than the reduced sample, has two reasons. First, it can be argued, from a radically descriptive point of view, that the age-based increase in dementia prevalence forms an integral part of *aging as a population process*. Therefore, if the goal is to describe changes in population parameters, the a priori exclusion of individuals who presumably suffer from some form of dementia leads to a less generalizable picture of age differences in intellectual functioning in old and very old age than results based on age-stratified random samples of the *total* population. The second reason is more methodological in kind. It is commonly assumed that the validity and reliability of a clinical diagnosis of dementia, especially in the very mild to moderate range and among the very old, is not perfect. For this reason, an a priori exclusion of subjects with a dementia diagnosis would have the unwanted consequence that subsequent



analyses are conditionalized upon an assessment that may not be more valid and reliable than many of the measures used thereafter.

3.1 Age Gradients of Intellectual Abilities in Old and Very Old Age

3.1.1 Overview

Figure 12.1 shows the age relations of the five intellectual abilities in a T -score metric ($M = 50$, $SD = 10$). The linear age relations of the unit-weighted composites ranged from $-.41$ for knowledge to $-.59$ for perceptual speed; for latent ability constructs, they ranged from $-.49$ (knowledge) to $-.61$ (perceptual speed). The magnitude of age relations was somewhat less pronounced when individuals with a clinical diagnosis of dementia were excluded from the analysis (see Table 12.2, and the thinner regression lines of the panels in Fig. 12.1). Quadratic age trends did not differ significantly from zero (perceptual speed: $r = .03$; reasoning: $r = .09$; memory: $r = .00$; knowledge: $r = .00$; fluency: $r = .00$;

Table 12.2. *Correlations between intellectual abilities and age (70–103 years)*

	Total sample (<i>N</i> = 516)		Excluding persons with dementia	
Mechanic intellectual abilities (broad fluid)				
Perceptual speed	-.59	(-.61)	-.54	(-.58)
Reasoning	-.51	(-.56)	-.44	(-.49)
Memory	-.49	(-.56)	-.39	(-.47)
Pragmatic intellectual abilities (broad crystallized)				
Knowledge	-.41	(-.49)	-.33	(-.41)
Fluency	-.46	(-.53)	-.40	(-.45)

Note. Values without parentheses refer to unit-weighted composites of the indicators, and correspond directly to Figure 12.1. Values in parentheses are based on a latent model positing five intercorrelated intellectual abilities with age as a correlate at the latent level (for details, see Lindenberger & Baltes, 1997).

all $ps > .01$), suggesting that relations between performance level and age were well captured by the linear age gradients shown in the five panels of Figure 12.1.

3.1.2 Ability-Specific Differences in the Magnitude of Age-Based Decrements: Mechanics versus Pragmatics

Table 12.2 reports the linear age relations of the five intellectual abilities. As expected, negative age relations were more pronounced for the three mechanic than for the two pragmatic abilities (for unit-weighted composites: $z = 4.98$, $p < .01$; for latent ability constructs: $z = 5.34$, $p < .01$).² Analyses with the reduced sample (i.e., after exclusion of subjects with dementia) led to analogous results (unit-weighted composites: $z = 4.33$, $p < .01$; latent ability constructs: $z = 4.80$, $p < .01$).

Within the three mechanic abilities, the age relation of perceptual speed ($r = -.59$) was more pronounced than the average age relations of reasoning ($r = -.51$) and memory ($r = -.49$; $z = 3.60$, $p < .01$). In contrast, the age gradients of the two more pragmatic abilities did not differ significantly from each other (knowledge: $r = -.41$; fluency: $r = -.46$; $z = 1.45$, $p > .10$). Analyses excluding individuals with dementia and analyses based on latent ability constructs provided analogous results.

With respect to cross-sectional age gradients, we conclude that the distinction between mechanic (broad fluid) and pragmatic (broad crystallized) intellectual abilities extends into old and very old age. However, compared with earlier periods of the life-span, the distinction in age trajectories appears to be less pronounced. Specifically, earlier differences in directionality (i.e., stability/decrements vs. stability/increments) are con-

²Differences between (sets of) correlated correlation coefficients were tested for statistical significance using the formulae proposed by Meng, Rosenthal, and Rubin (1992). For instance, differences in the age relations of mechanic and pragmatic abilities were tested with Formula (8) of Meng et al. (1992). This formula allows researchers to specify a contrast to test whether one set of variables (e.g., mechanic abilities) is more highly related to a criterion variable (e.g., age) than another set of variables (e.g., pragmatic abilities).

verted into different degrees of linear decrement. In this context, it is important to note that the three tests of knowledge were administered without any external constraints on testing time, and that instructions, if necessary, were repeated to make sure that participants knew what they were supposed to do. Thus, it is difficult to argue that the negative age gradient for knowledge primarily reflects the operation of age-associated but ability-extraneous performance factors.

3.1.3 Examination of Gender Differences in Level and Age Relations of Intellectual Functioning

Hierarchical regression analyses were computed to examine the possible existence of gender differences in the level and the age relations of intellectual functioning for each of the five intellectual abilities. Due to stratification, age and gender were orthogonal in this sample (average age for men = 84.7 years; average age for women = 85.1 years; correlation between gender and age: $r = .02$, n.s.). Therefore, age, gender, and the age-by-gender interaction orthogonalized with respect to the two main effects were entered simultaneously into the linear regression equation.

In addition to main effects of age, which, reflecting the orthogonality of the predictors, were identical to those reported before, we observed two main effects of gender, one for reasoning and the other for knowledge. In both cases, men had significantly higher scores than women (reasoning: $\beta = -.13$, $t = -3.37$, $p < .002$; knowledge: $\beta = -.15$, $t = -3.68$, $p < .002$; p -values are Bonferroni-adjusted, i.e., $.01/5$). When expressed in standard deviation units [i.e., $(\text{mean}_{\text{men}} - \text{mean}_{\text{women}}) / SD_{\text{pooled}}$], the effect size of the male advantage was .28 for reasoning and .31 for knowledge. None of the remaining effects were significant. Specifically, there were no indications that age gradients differed significantly as a function of gender.

A possible reason for the observed male advantage refers to the existence of historically stable gender-linked inequalities in societal opportunity structures such as access to formal education. On average, men had received more education than women (men: $M = 11.3$ years, $SD = 2.5$; women: $M = 10.2$ years, $SD = 2.0$; $t = -5.62$, $p < .01$). In accordance with the social-inequality interpretation, gender differences in reasoning and knowledge were no longer significant after statistically controlling for individual differences in education (reasoning: $\beta = -.05$, $t = -1.48$, $p = .14$; knowledge: $\beta = -.06$, $t = -1.66$, $p = .10$). However, we now noticed a significant *female* advantage for memory ($\beta = .12$, $t = 3.13$, $p < .002$). Possibly, this female advantage had been masked by gender-linked individual differences in years of education in the original analysis. Note that the existence of a small but reliable episodic-memory advantage for women is consistent with findings from several other large-scale studies on memory functioning during adulthood and old age (Herlitz, Nilsson, & Bäckman, 1997).

3.2 The Structure of Intellectual Abilities in Old and Very Old Age

We now turn to the structural properties of intellectual functioning in old and very old age. We inspect the intercorrelations of the five intellectual abilities, propose a structural model to capture the structure of old-age intelligence in a more formal manner, and examine possible age differences in ability intercorrelations and interindividual variability.

Table 12.3. *Intercorrelations among intellectual abilities*

	Perceptual speed	Reasoning	Memory	Knowledge	Fluency
Perceptual speed	—	.72 (.82)	.71 (.85)	.71 (.83)	.73 (.85)
Reasoning	.60 (.73)	—	.64 (.80)	.70 (.86)	.63 (.77)
Memory	.60 (.77)	.52 (.71)	—	.66 (.84)	.70 (.89)
Knowledge	.64 (.77)	.62 (.81)	.58 (.79)	—	.70 (.87)
Fluency	.64 (.79)	.52 (.68)	.61 (.84)	.63 (.83)	—

Note. $N = 516$. First-order correlations are shown above, age-partialled correlations below the main diagonal. Values without parentheses refer to unit-weighted composites, values in parentheses to intercorrelated latent factors (for details, see Lindenberger & Baltes, 1997).

3.2.1 *Intercorrelations of Intellectual Abilities*

Table 12.3 reports the intercorrelations among the five intellectual abilities. Correlations were high and uniform throughout all five abilities. For instance, at the level of unit-weighted composites, the median correlation among the five intellectual abilities was $r = .70$, the lowest correlation was $r = .63$, and the highest correlation was $r = .73$. When performing an exploratory factor analysis with principal components extraction over the five unit-weighted ability scores, the first unrotated factor accounted for 75% of the total variance. Finally, at the level of latent constructs (e.g., after correcting for unreliability), the median correlation was $r = .85$, the lowest correlation was $r = .77$, and the highest correlation was $r = .89$.

The magnitude of these intercorrelations is higher than the range commonly observed during earlier phases of the adult life-span (cf. Carroll, 1993). For the purpose of comparison, a recent study from our own laboratory is particularly useful. In that study (P. B. Baltes & Lindenberger, 1997), we administered the identical battery of cognitive tests to a heterogeneous sample of 171 adults aged 25 to 69 years. Using unit-weighted composites, the median intercorrelation among the five intellectual abilities was $r = .38$, the lowest correlation was $r = .22$, and the highest correlation was $r = .42$.

In addition to sheer magnitude, another important feature of the correlational structure was its homogeneity. For instance, correlations *within* mechanic and pragmatic domains were not higher than correlations *between* the two domains (median correlation between perceptual speed, reasoning, and memory: $r = .71$; correlation between knowledge and fluency: $r = .70$; median correlation between the two domains: $r = .70$). Thus, in contrast to age relations, the pattern of intercorrelations did not follow the mechanic-pragmatic distinction.

The finding of uniformly high ability intercorrelations extends the results of earlier studies on age differences in ability intercorrelations (P. B. Baltes et al., 1980; Schaie, Willis, Jay, & Chipuer, 1989), and gives further support to the dedifferentiation or neointegration hypothesis of old-age intelligence (P. B. Baltes et al., 1980, 1998; Deary & Pagliari, 1991; Lienert & Crott, 1964; Reinert, 1970; cf. Garrett, 1946; Spearman, 1927). From a methodological point of view, however, one may object that the magnitude of

ability intercorrelations represents little more than the necessary consequence of the magnitude and uniformity of the age relations of the five abilities (Lindenberger & Pötter, 1998; Merz & Kalveram, 1965; Reinert, Baltes, & Schmidt, 1966). To examine this possibility, we also inspected the age-partialled intercorrelations among the five intellectual abilities (see Table 12.3). Ability intercorrelations were lowered by controlling for age, but they still were of greater magnitude and uniformity than comparable correlations during earlier periods of the adult life-span. At the level of unit-weighted composites, the median correlation was $r = .61$, the lowest correlation was $r = .52$, and the highest correlation was $r = .64$. When performing an exploratory factor analysis with principal components extraction over the five age-partialled ability scores, the first unrotated factor still accounted for 68% of the total variance. And finally, when controlling for age at the latent level, we observed a median correlation of $r = .78$.

One may also object that the presence of individuals diagnosed with dementia who scored low across all tests of the battery may have boosted the magnitude of ability intercorrelations. To explore this issue, we examined the magnitude of ability intercorrelations after excluding participants with a clinical diagnosis of dementia ($n = 109$). In the reduced sample ($n = 407$), we observed a median correlation for unit-weighted composites of $r = .61$ before and of $r = .54$ after controlling for individual differences in chronological age (latent level: $r = .79$ vs. $r = .73$).

In sum, the presence of strong and uniform age relations and the inclusion of individuals with a clinical diagnosis of dementia did, in fact, contribute a significant share to the magnitude of ability intercorrelations observed in this sample. However, the magnitude and uniformity of ability intercorrelations remained substantial after controlling for both of these factors, and clearly exceeded the range of ability intercorrelations observed in younger age groups of comparable heterogeneity. Based on this evidence, we conclude that differences in intellectual functioning in old and very old age show a much greater degree of consistency (homogeneity) across abilities and ability domains than differences in intellectual functioning during earlier periods of the adult life-span. In fact, as documented in detail elsewhere (Lindenberger & Baltes, 1997), the observed intellectual-ability intercorrelations can be adequately represented by a hierarchical model of intelligence which posits the existence of a unitary factor of general intelligence, or g , at the second-order level (see Fig. 7.1 in Smith & Baltes, Chapter 7).

3.2.2 Age Differences in Ability Intercorrelations

To examine the possible existence of age-based differences in covariation among the five intellectual abilities *within* the BASE age spectrum, the total sample was split into two subsamples, one labeled as *old* ($n = 258$, mean age = 77.5 years, $SD = 4.3$, age range = 70–84 years) and the other as *very old* ($n = 258$, mean age = 92.4 years, $SD = 4.5$, age range = 85–103 years). First, we compared the magnitude of intellectual-ability intercorrelations in the two groups at the level of unit-weighted composites. The median correlation was .62 in the old and .63 in the very old sample, and there was no evidence for significant differences in the magnitude of ability intercorrelations between the two groups. When individuals with dementia were excluded from the analysis, the median correlation was .55 in the old group ($n = 236$, mean age = 77.2 years, $SD = 4.3$) and .57 in the very old group ($n = 171$, mean age = 91.8 years, $SD = 3.5$). Differences between groups were again not significant. Analyses based on two-group structural models led to compa-

rable results (cf. Lindenberger & Baltes, 1997). Thus, results did not indicate a further increase in ability intercorrelations from old to very old age. Possibly, selective mortality counteracted any subsisting tendency toward continuing dedifferentiation (for more discussion and an analysis of age and ability differences in *intraindividual* task variability, cf. Lindenberger & Baltes, 1997).

3.2.3 Age Differences in Interindividual Variability

As reported above, about a third of the interindividual variability in intellectual functioning was related to chronological age. The highest relationship was found for perceptual speed, where age accounted for 38% of the reliable variance. By implication, however, this also means that a substantial portion of interindividual differences was *not* related to chronological age, as demonstrated by the large amount of scatter around the regression lines in Figure 12.1. In fact, a few individuals performed exceptionally well for their age. For instance, with respect to perceptual speed, a 95-year-old performed 1.0 standard deviation units above the mean of the 70-year-olds and 1.5 standard deviation units above the mean of the total sample. Another example is an 89-year-old who, together with a 73-year-old and a 77-year-old, obtained the highest score on the reasoning factor.

To examine whether the amount of interindividual variability increased or decreased with age, we regressed each of the five intellectual abilities and the unit-weighted composite of the five abilities (i.e., general intelligence) on age. To obtain a measure of interindividual variability, we then computed the rank order of the absolute deviations from each of the six regression lines.

Overall, the magnitude of interindividual variability was remarkably stable (see also Table 5 in Lindenberger & Baltes, 1997). Specifically, perceptual speed, fluency, memory, and the general-intelligence composite did not evince any significant changes in interindividual variability with advancing age. Interindividual variability decreased with respect to reasoning ($r = -.30, p < .01$), and slightly increased with respect to knowledge ($r = .13, p < .01$). Further analyses not reported here showed that the observed pattern of results most likely was not entirely attributable to floor or ceiling effects. For instance, the decrease in interindividual variability for reasoning continued to be significant after excluding individuals diagnosed with dementia ($r = -.25, p < .01$) or after excluding all individuals with either missing values or zero scores on any one of the three tests of reasoning ($r = -.19, p < .01$). In sum, results indicate that interindividual heterogeneity subsists into very old age, but do not lend support to the stronger claim that individuals become generally more dissimilar as they age (cf. Christensen et al., 1994; Nelson & Dannefer, 1992).

3.3 Correlates of Intellectual Functioning in Old and Very Old Age

We now turn to the correlates of intellectual functioning in old and very old age. Many theoretical conceptions about the structure and life-span ontogenesis of intellectual functioning posit two interrelated but distinct systems of influence: the biological and the cultural. The two systems are seen as antecedents, correlates, and consequents of intellectual functioning. They jointly contribute to the overdetermined or "compound" (Horn, 1989) character of human intelligence (P. B. Baltes, 1987, 1997; cf. P. B. Baltes et al., 1998; Cattell, 1971; Horn, 1982).

In line with these conceptions, we expect that mechanic and pragmatic intellectual abilities are differentially related to biological and sociobiographical correlates. Specifically, we assume that knowledge, as a key marker ability of the pragmatic (broad crystallized) domain, should be closely related to individual differences in past and concurrent sociostructural status and experience. On the other hand, perceptual speed, as a marker ability of the mechanics, should evince a particularly close link to cognition-extraneous indicators of aging-induced biological decrements in brain functioning.

Within the presumably more biologically dominated set of correlates, balance/gait, hearing, and vision were chosen to represent individual differences in the domain of sensory-sensorimotor functioning. As expected, the three sensory-sensorimotor variables and the four sociobiographical variables (i.e., income, social prestige, social class, and years of education) fell into two distinct groups. For instance, an exploratory factor analysis (i.e., principal axis extraction followed by oblique rotation) yielded two, moderately intercorrelated factors ($r = .26$). The divergent nature of the two sets of correlates was further corroborated by the fact that the sensory-sensorimotor variables, but not the sociobiographical variables, were substantially related to chronological age.

3.3.1 *The Effect of Life-History Differences on Negative Age Differences in Intellectual Functioning Late in Life: Is Age Kinder to the Initially or Currently Advantaged?*

A recurring hypothesis in gerontological research is that individuals with high standing on desirable life-history or sociobiographical dimensions such as social status, social participation, or initial level of cognitive functioning are less likely to experience age-associated decrements in intellectual performance than individuals who score low on any one of these dimensions. According to this line of thought, age is “kinder to the initially more able” (Owens, 1959). Most of the available longitudinal and cross-sectional evidence on this issue does not lend support to this expectation. Instead, with some notable exceptions (e.g., Kohn & Schooler, 1978), the results of numerous investigations seem to suggest that individuals scoring high on desirable dimensions show similar amounts of age changes or age differences as individuals with relatively low scores (for a review, cf. Salthouse, 1991). However, for old and very old age little information about this issue has been available on the same dimensions.

In the BASE sample, all four sociobiographical life-history variables were positively related to general intelligence (see Table 12.4). Among the four, years of education and social prestige were more highly correlated with general intelligence than social class and income ($z = 3.64$, $p < .01$). The multiple correlation of the four correlates with general intelligence was substantial, $R = .48$, $p < .01$. To examine the link of the sociobiographical factors to general intelligence, we computed a unit-weighted composite over the four sociobiographical variables, and compared individuals who scored above the mean ($n = 234$) with those who scored below ($n = 282$). The difference in general intelligence between these two groups amounted to somewhat less than a standard deviation, $E_{SD} = 0.91$, $t = 10.27$, $p < .01$.

As is shown in Figure 12.2, the slope of the cross-sectional age gradients in general intelligence observed in this data set did not vary significantly as a function of social life-history information. The figure displays two freely estimated regression lines, one for individuals above and the other for individuals below the mean on the index of socio-

Table 12.4. *Correlates of general intelligence in old and very old age*

Domain	<i>g</i>	<i>g</i> (age-partialed)	Age
Sociobiographical variables			
Social prestige	.41	.44	-.08
Years of education	.39	.38	.14
Social class	.29	.35	.00
Income	.28	.31	-.04
Multiple correlation (<i>R</i>)	.48		
Sensory-sensorimotor variables			
Balance/gait	.59	.36	-.66
Hearing	.51	.28	-.57
Vision	.57	.36	-.59
Multiple correlation (<i>R</i>)	.69		
Other medical-biological variables			
Brain atrophy index ^a	-.44	-.20	.51
Number of diagnoses	-.14	-.08	.13
Amount of medication	-.00	.04	.05

Note. *N* = 516. Values not significantly different from zero are in italics.

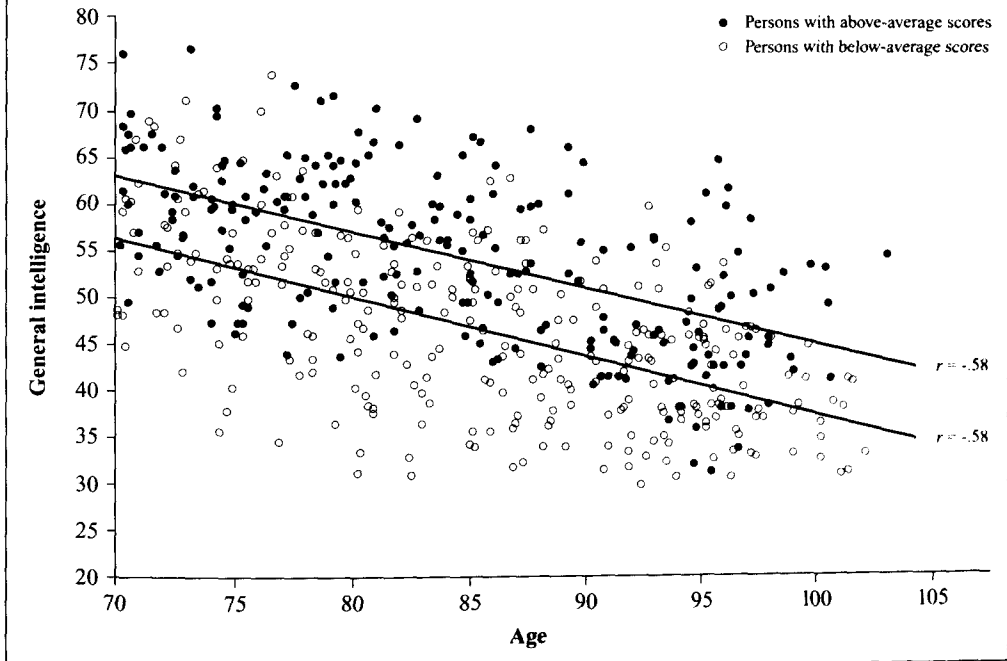
^a*n* = 254.

biographical differentiation introduced above. The relation of general intelligence to age was identical in the two groups, $r = .58$.³

On the one hand, then, past and present sociocultural differences continue to be associated with interindividual differences in intellectual functioning after age 70. On the other hand, there was no evidence in this cross-sectional analysis to suggest that advantages in life history and current sociocultural context protect against age-based reductions in intellectual performance. From a psychometric perspective, our findings suggest that the life periods of old and very old age are not kinder to the initially or presently advantaged. However, a *threshold view* of the matter, which may be more adequate for a variety of practical, ethical, or theoretical reasons, may lead to an opposite interpretation of the same data pattern. According to that interpretation, the sociobiographically more advantaged are much less likely to end up with levels of intelligence that no longer permit an independent life, just because they carry a (presumably constant) advantage into very old age (cf. M. M. Baltes et al., Chapter 14).

³To examine the robustness and the generality of this finding, additional analyses were computed using other statistical procedures (e.g., hierarchical regression with a continuous, rather than dichotomous, representation of the independent variable; two-group structural models), different dependent variables (perceptual speed and knowledge, rather than general intelligence), and different independent variables (personality variables such as openness to experience, extraversion, and neuroticism; social participation; age-corrected intelligence). Without exception, interactions with age fell far from statistical significance.

Figure 12.2. Is age kinder to the socially and biographically advantaged (cf. Owens, 1959)? Perhaps not. The figure displays the freely estimated regression lines of general intelligence on age for individuals who performed above (filled circles) and below (unfilled circles) the mean on a unit-weighted composite of four sociobiographical indicators. Adapted from Lindenberger and Baltes (1997).



3.3.2 Biological Factors: The Intersystemic Link to Sensory and Sensorimotor Functions

As can be seen in Table 12.4, the three sensory-sensorimotor variables showed an even more substantial link to general intelligence than the sociobiographical life-history variables, multiple $R = .69$. In contrast, general somatic morbidity was only weakly related to intelligence ($r = -.14, p < .01$), and amount of medication did not show a significant relationship ($r = .00$).

In addition to being strongly related to general intelligence, the sensory-sensorimotor variables and the index of brain atrophy were also strongly related to age. One way to illustrate the predominantly age-based character of the connection between the sensory-sensorimotor variables and general intelligence is to compare the age gradients of general intelligence before and after controlling for individual differences in vision, hearing, and balance/gait. Controlling for individual differences on these three variables reduced the age relation from $r = -.57$ to $r = -.06$ ($p > .05$). In other words, the proportion of the total age-related variance in general intelligence that was shared with vision, hearing, and/or balance/gait did not differ significantly from 100% (e.g., perfect overlap; for methodological caveats in interpreting the results of hierarchical regression, cf. Lindenberger & Pötter, 1998).

In sum, these analyses replicate earlier findings based on the initial subsample of 156 BASE participants (Lindenberger & Baltes, 1994b), demonstrating again that indicators of sensory-sensorimotor functioning emerge as powerful correlates of intelligence in old and very old age. One may wonder whether the magnitude of these relations was primarily due to the fact that a substantial portion of the total sample suffered from very poor hearing or very poor vision (cf. Marsiske et al., Chapter 13). However, additional control analyses found no evidence to suggest that associations between sensory-sensorimotor functioning, general intelligence, and age decreased with increasing sensory-sensorimotor or intellectual performance levels (cf. Lindenberger & Baltes, 1994b).

Elsewhere (P. B. Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994b), we have argued that the magnitude and the age-relatedness of this intersystemic connection point to the existence of a set of more general, brain-related mechanisms which regulate the aging process in both domains. From this perspective, the sensory-sensorimotor variables are good predictors (in the statistical sense) of age-based differences in general intelligence in old and very old age because they happen to be good indicators of this general set of mechanisms. This interpretation receives additional support by the significant connection of brain atrophy to intelligence and age (cf. Raz et al., 1993).

3.3.3 Ability-Specific Relations to Sociobiographical and Sensory-Sensorimotor Variables: Evidence for Divergent External Validity

We now turn to the issue whether the sociobiographical and sensory-sensorimotor variables assessed in this study were differentially related to mechanic and pragmatic intellectual abilities, as two-component models of intellectual development would predict (P. B. Baltes, 1987, 1997). In a first analysis, we chose knowledge as a marker ability of the cognitive pragmatics and perceptual speed as a marker of the cognitive mechanics to examine whether these two intellectual abilities were differentially related to sensory-sensorimotor and sociobiographical variables. The selection of these two intellectual abilities was guided by theoretical and empirical considerations. Thus, perceptual speed is generally regarded as a highly aging-sensitive ability in the broad fluid domain (Salt-house, 1991), whereas general semantic knowledge is often seen as a reliably measured and socially relevant ontogenetic acquisition.

The emerging correlational pattern was fully consistent with our expectations (see Fig. 7.3 in Smith & Baltes, Chapter 7): Perceptual speed evinced stronger relations to the sensory-sensorimotor variables than knowledge, and knowledge was more strongly related to the sociobiographical variables than perceptual speed. The relevant statistical tests, which compared the correlations of perceptual speed and knowledge with the seven variables, were significant throughout: balance/gait: $z = 5.88$; hearing: $z = 2.75$; vision: $z = 3.69$; income: $z = -2.40$; social prestige: $z = -4.14$; social class: $z = -3.37$; years of education: $z = -3.15$; for all z -values, $p < .01$.

These analyses clearly demonstrate that perceptual speed and knowledge were differentially related to sociobiographical and sensory-sensorimotor correlates of intellectual functioning. Specifically, at least two of the five intellectual abilities assessed in this study displayed meaningful specificity despite the fact that more than 80% of their reliable variance was shared with other intellectual abilities.

Another outcome of this analysis was that both perceptual speed and knowledge appeared to be more strongly related to sensory-sensorimotor functioning than to sociobiographical differences, suggesting a preponderance of sensory-sensorimotor over so-

Table 12.5. *Relations of intellectual abilities to sociobiographical and sensory-sensorimotor correlates: Amounts of shared variance (%) between latent constructs*

	Socio- biographical	Sensory- sensorimotor	z-value
Mechanic intellectual abilities (broad fluid)			
Perceptual speed	19.4	72.4	13.46
Reasoning	22.8	57.9	8.28
Memory	17.7	52.6	8.24
Pragmatic intellectual abilities (broad crystallized)			
Knowledge	37.5	50.4	3.01
Fluency	22.7	59.9	8.83
Average of all five intellectual abilities			
	23.9	59.1	8.34

Note. Results are based on a measurement model with a latent factor of sociobiographical differentiation defined by income, social prestige, social class, and years of education, a latent factor of sensory-sensorimotor functioning defined by balance/gait, hearing, and vision, and five intellectual-ability factors defined by the corresponding tests. The fit of the model was acceptable, $\chi^2(166, 516) = 304.14$, NNFI = .974, CFI = .979, AODSR = .023. The sociobiographical and the sensory-sensorimotor factors had 11.8% of their variance in common. As indicated by the z-values, all five intellectual abilities were more strongly associated with sensory-sensorimotor functioning than with the sociobiographical factor. For further details, see Lindenberger and Baltes (1997).

ciobiographical differences with respect to all five intellectual abilities. To examine this issue more closely, and to control better for differences in reliability between the two sets of correlates, we set up a latent model with a factor of sensory-sensorimotor functioning defined by balance/gait, hearing, and vision, a sociobiographical factor defined by income, social prestige, social class, and years of education, and the five intellectual-ability factors defined by their corresponding tests. The fit of this model was quite acceptable; $\chi^2(166, 516) = 304.14$, NNFI = .974, CFI = .979, AODSR = .023.

Table 12.5 displays the amount of reliable (i.e., latent-factor) variance shared between the five intellectual abilities, on the one hand, and sensory-sensorimotor functioning and a sociobiographical factor, on the other. Three findings are noteworthy. First, all five intellectual abilities were again more strongly related to sensory-sensorimotor functioning than to the sociobiographical factor, suggesting that the previous finding for knowledge and perceptual speed was not only due to differences in reliability between the two sets of correlates. The magnitude of the relationship between perceptual speed and sensory-sensorimotor functioning was especially impressive: The two constructs shared 72% of their variance. Second, we replicated the finding that the link between perceptual speed and sensory-sensorimotor functioning was more pronounced than the link between knowledge and sensory-sensorimotor functioning ($z = 9.64, p < .01$). Likewise, the link between knowledge and sociobiographical differences was more pronounced than the link between perceptual speed and the sociobiographical factor ($z = 7.95, p < .01$). Fi-

nally, the remaining three intellectual abilities showed less distinct correlational profiles, and there was some unexpected crossover between mechanic and pragmatic abilities. Specifically, fluency was more strongly related to sensory-sensorimotor functioning than memory ($z = 3.64, p < .01$), but did not differ from reasoning in its relation to the sociobiographical factor status ($z = 0.04, p > .10$), which provides further support for the hybrid, rather than predominantly pragmatic, nature of fluency (Salthouse, 1993).

3.3.4 *Correlates of Intellectual Functioning in Old and Very Old Age:*

A Summary Model

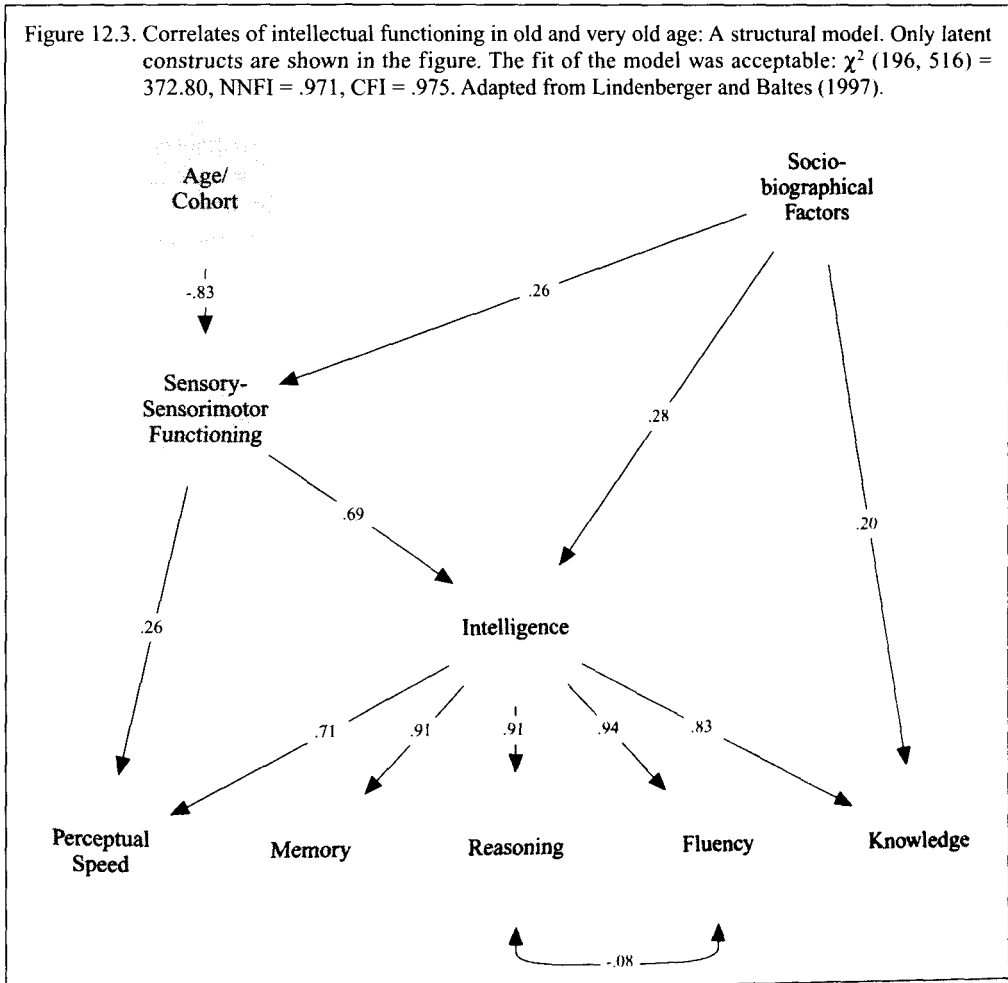
To summarize relations among age, sensory-sensorimotor functioning, sociobiographical differences, and intelligence in this data set we conclude this section with an overall structural model. As before, sociobiographical differences were indexed by social class, education, social prestige, and income, sensory-sensorimotor functioning by vision, hearing, and balance/gait, and the five intellectual abilities by the corresponding tests. The structural relations among the latent constructs of the model are shown in Figure 12.3.

In this model, chronological age and the sociobiographical factor function as independent variables. It is assumed that age differences in intelligence are connected to sensory-sensorimotor functioning to such a degree that all of the age-related variance in intellectual functioning is shared with the sensory-sensorimotor factor (i.e., it is assumed that the unique effects of age on intellectual functioning after controlling for individual differences in sensory-sensorimotor functioning do not differ significantly from zero). In addition, we expected a specific link between sensory-sensorimotor functioning and perceptual speed, reflecting the close connection between the two domains of functioning. Finally, the sociobiographical factor was related to general intelligence, but also to the sensory-sensorimotor factor. In addition, individual differences captured by the sociobiographical factor were assumed to be specifically linked to knowledge.

The resulting model fits the data quite well, $\chi^2(196, 516) = 372.80$, NNFI = .971, CFI = .975, AODSR = .037, and explained 66% of the total reliable variance in general intelligence. Note that all the links between latent constructs that are missing in this model, such as the link between age and the sociobiographical factor (whose presence would have pointed to the existence of cohort effects), links from age to general intelligence or from age to the five intellectual abilities, and the remaining links from sensory-sensorimotor functioning and the sociobiographical factor to any of the five intellectual abilities, did not differ significantly from zero (i.e., all $ps > .01$).

4 **Cognitive Aging with and without Dementia: Direct Comparisons**

So far, participants with a clinical diagnosis of dementia were routinely included in the analyses reported in this chapter. This procedure was justified by the argument that aging, as a population process, comprises individuals with and without dementia, and that the reliability and validity of any clinical diagnosis of dementia is not perfect. Nevertheless, it is of interest to examine how individuals diagnosed with dementia differed from other individuals, especially after controlling for age differences between the two groups. In the following, we report three ways to address this issue. First, we examine whether dementia diagnosis and dementia severity were differentially related to the five intellectual abilities assessed by the psychometric test battery. Second, we test the hypothesis that measures of episodic recall performance and learning poten-



tial that were designed with the specific goal to be sensitive to individual differences in effective cue utilization, or encoding specificity (Buschke et al., 1995, 1997), such as the ECR test (Grober et al., 1988) used in this study, are especially effective in discriminating between individuals with and without dementia. Third, we report a mixture distribution analysis of the SMMS (Reischies, Schaub, & Schlattmann, 1996) suggesting that the performance distributions of individuals with and without dementia are distinct but appear to converge with advancing age.

4.1 Relationship of Intellectual Abilities to Dementia Diagnosis and Dementia Severity

In the total sample, point-biserial correlations of dementia diagnosis (0 = absent, 1 = present) with intellectual functioning were as follows: memory, $r = -.53$; per-

ceptual speed, $r = -.52$; fluency, $r = -.50$; knowledge, $r = -.49$; reasoning, $r = -.40$. After controlling for age, relations were reduced in magnitude: memory, $r = -.43$; fluency, $r = -.41$; perceptual speed, $r = -.40$; knowledge, $r = -.40$; reasoning, $r = -.28$. Contrary to expectations (cf. Christensen, Hadzi-Pavlovic, & Jacomb, 1991), memory, in this set of analyses, did not differ significantly in its relation to dementia diagnosis from fluency, perceptual speed, and knowledge (first-order correlations: $z = 1.02$, $p > .10$; age-partialed correlations: $z = 0.93$, $p > .10$). However, reasoning was more weakly related to dementia diagnosis than the other four intellectual abilities (first-order correlations: $z = 4.50$, $p < .01$; age-partialed correlations: $z = 4.69$, $p < .01$).

Within the group of individuals with dementia diagnosis ($n = 109$), the degree of dementia severity (1 = very mild to mild, 2 = moderate, 3 = severe) was negatively related to all five intellectual abilities (raw correlations: memory, $r = -.53$; fluency, $r = -.50$; perceptual speed, $r = -.42$; knowledge, $r = -.29$; reasoning, $r = -.29$; age-partialed correlations: memory, $r = -.52$; fluency, $r = -.49$; perceptual speed, $r = -.40$; knowledge, $r = -.28$; reasoning, $r = -.28$). Consistent with expectations (Christensen et al., 1991), memory and fluency were more highly related to dementia severity than reasoning, knowledge, and perceptual speed (raw correlations: $z = 3.35$, $p < .01$; age-partialed correlations: $z = 3.36$, $p < .01$).

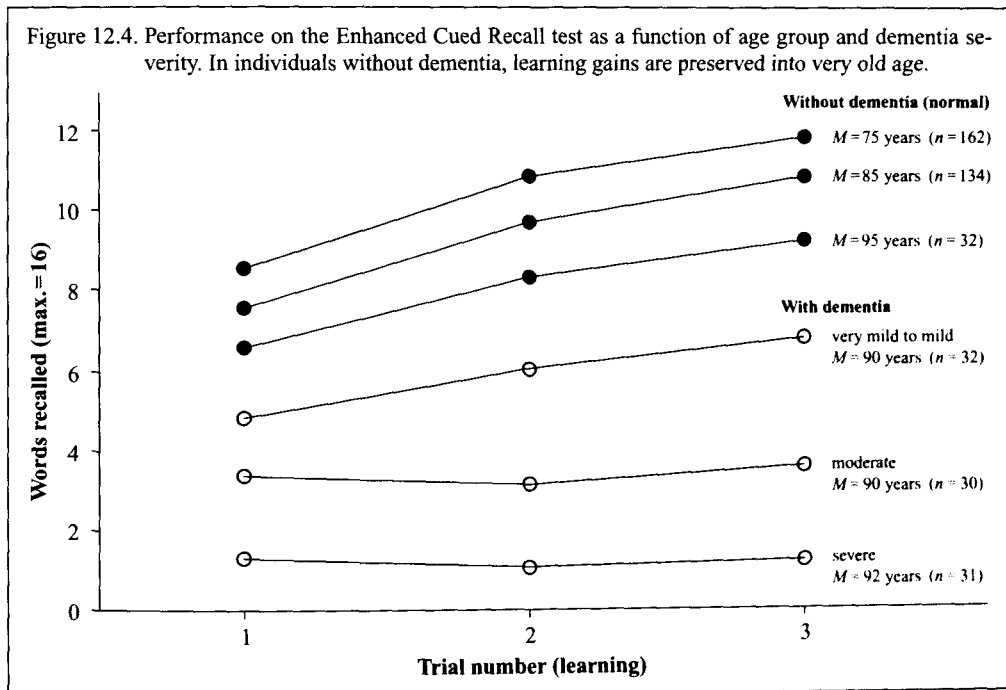
4.2 Cue Utilization in Episodic Memory and Learning: Does It Dissociate Normal Aging from Dementia?

Disproportionately large losses in the ability to learn and remember are often regarded as the central characteristic of dementing disorders. In this context, recent investigations suggest that the ability to profit from environmental support, such as the provision of category cues during encoding retrieval, is differentially impaired in individuals with dementia (Grober & Kawas, 1997). Whereas older adults without dementia appear to make effective use of these cues, and are able to achieve relatively high levels of recall performance after repeated exposure to the to-be-learned items, persons with dementia profit much less from this form of environmental support. According to one interpretation (Buschke et al., 1995, 1997), this suggests that individuals with dementia show specific impairments in the ability to encode to-be-learned materials in a specific (e.g., discriminable or distinct) manner.

4.2.1 Analysis of Recall Level and Learning Gain in the ECR Test

To examine whether initial memory performance and learning gain under supportive conditions differed as a function of dementia status and/or age, we analyzed the trial-by-trial memory performance on the ECR test under conditions of cued encoding and recall. Six groups were distinguished: (a) three age groups of persons without dementia, 70- to 79-year-olds ($n = 162$, mean age = 74.9), 80- to 89-year-olds ($n = 134$, mean age = 84.7), and persons aged 90 and over ($n = 88$, mean age = 94.5); (b) three groups of persons with a diagnosis of very mild to mild ($n = 32$, mean age = 89.6), moderate ($n = 30$, mean age = 89.6), or severe ($n = 31$, mean age = 92.1) dementia. Due to missing data, only 477 individuals were included in this analysis.

A repeated-measures ANOVA with Trial (3) as a within-subjects factor and Group (6) as a between-subjects factor was used to analyze recall performance. A series of five a



priori orthogonal contrasts was specified for the Group factor. The first contrast tested individuals without dementia diagnosis versus individuals with a dementia diagnosis. The second and third contrasts tested effects of age *within* individuals without dementia (contrast 2: 70–79 vs. 80+; contrast 3: 80–89 vs. 90+). The fourth and fifth contrasts tested effects of dementia severity (contrast 4: very mild to mild vs. moderate or severe; contrast 5: moderate vs. severe).

The results of the analysis of variance were remarkably clear (see Fig. 12.4). In persons without dementia, recall performance decreased with advancing age, but this decrement did not interact with Trial, indicating that age differences in learning gain were not significant (*Group*: 70–79 vs. 80+: $F(1, 471) = 44.9, p < .01$; 80–89 vs. 90+: $F(1, 471) = 16.0, p < .01$; *Group* \times *Trial*: 70–79 vs. 80+: $F(2, 942) = 0.8, p > .10$; 80–89 vs. 90+: $F(2, 942) = 1.9, p > .10$). In contrast, the comparison of persons with and without a dementia diagnosis revealed both a difference in performance levels as well as a difference in learning gain (*Group* $F(1, 471) = 411.4, p < .01$; *Group* \times *Trial*: $F(2, 942) = 36.4, p < .01$). Within the dementia subsample, persons with very mild to mild dementia differed from those with moderate or severe dementia with respect to both performance level and learning gain (*Group*: $F(1, 471) = 45.2, p < .01$; *Group* \times *Trial*: $F(2, 942) = 6.8, p < .01$). Finally, the comparison between individuals with moderate and severe dementia revealed differences in performance level, *Group*: $F(1, 471) = 11.5, p < .01$, but not in learning gain, *Group* \times *Trial*: $F(2, 942) = 0.11, p > .10$. In fact, a post hoc analysis revealed that the recall performance of those with moderate and severe dementia did not significantly improve across the three trials ($F(2, 118) = 1.23, p > .10$).

In sum, the results of this analysis indicate that age and dementia have dissociable effects on recall level and learning gain. In individuals without dementia, increasing age was associated with lower *levels of recall*, but not with a decrement in the ability to profit from repeated exposure to to-be-learned materials. In contrast, individuals with moderate or severe dementia not only showed lower levels of initial recall performance, but also a drastic reduction in learning gain – in fact, no learning at all (cf. Reischies, Geiselman, & Lindenberger, 1998).

4.2.2 *Predicting Dementia Status: The Specific Contribution of ECR Learning Gain*

The discriminating power of learning gain was further confirmed by logistic regression analyses using dementia status (0 = absent, 1 = present) as the dependent variable. Three variables were considered as predictors of dementia status: (a) the intellectual-ability composite of perceptual speed, which can be regarded as a marker variable of normal negative age differences in adult cognition (Salthouse, 1996); (b) recall level at Trial 1 of the ECR test; (c) learning gain in the ECR test, that is, the difference between Trial 3 and Trial 1. Perceptual speed was entered first and was found to predict dementia status, $\chi^2(1, 477) = 135.9, p < .01$. Adding ECR recall at Trial 1 significantly reduced the number of misclassified individuals (i.e., false positives and misses) from 72 to 56, $\chi^2(1, 477) = 62.3, p < .01$. Finally, entering ECR learning gain in the third step led to a small, but significant further reduction of misclassified individuals from 56 to 52, $\chi^2(1, 477) = 36.6, p < .01$.

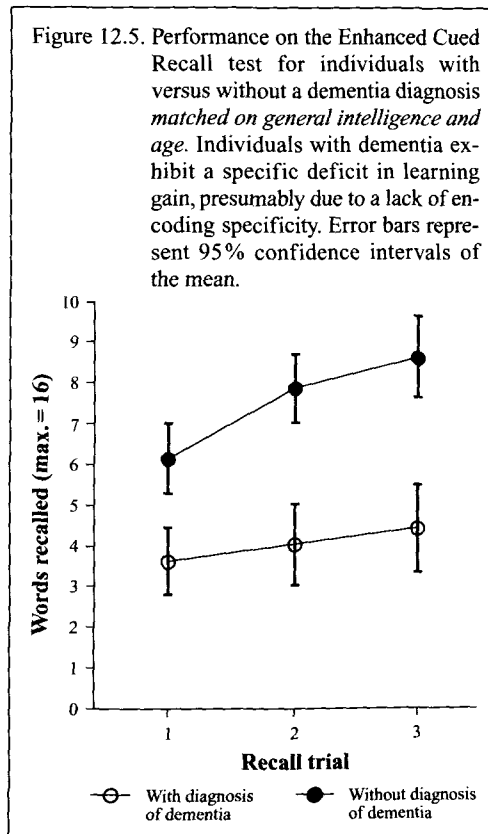
4.2.3 *Matched-Control Analysis*

The design of BASE enables us to compare individuals with and without a dementia diagnosis who do *not* differ on the general factor of intelligence and age. Specifically, we matched individuals of similar age and with close-to-identical levels of performance on the general factor of intelligence as defined by the psychometric test battery in a pairwise fashion (i.e., persons with and without dementia). Application of this procedure resulted in 70 pairs. The two groups did not differ in general intelligence ($T_{\text{no dementia}} = 41.9$ vs. $T_{\text{dementia}} = 42.0, t = -1.62$) or age ($Age_{\text{no dementia}} = 89.0$ vs. $Age_{\text{dementia}} = 90.7, t = -1.52$; *t*-values refer to dependent *t*-tests). The scores of the remaining 39 participants with dementia were too low to be matched with a control.

Figure 12.5 shows the recall performance on the ECR test, which was *not* used to assemble the pairs, for the two groups. Despite the equivalence of the two groups in general intelligence and age, significant differences in recall level and learning gain were observed (*Group*: $F(1, 471) = 16.95, p < .01$; *Group* \times *Trial*: $F(2, 110) = 4.54, p = .013$).

4.2.4 *Summary of ECR Analyses*

Taken together, the findings obtained with the ECR test support the view that memory-related functioning in older individuals with dementia differs from memory-related functioning in older adults without dementia. Specifically, the findings suggest that the ability to learn from experience (M. M. Baltes, K uhl, & Sowarka, 1992; Willis & Nesselrode, 1990) is disproportionately reduced in persons with dementia, perhaps as a consequence of a disproportionate impairment in mnemonic processes that foster encoding

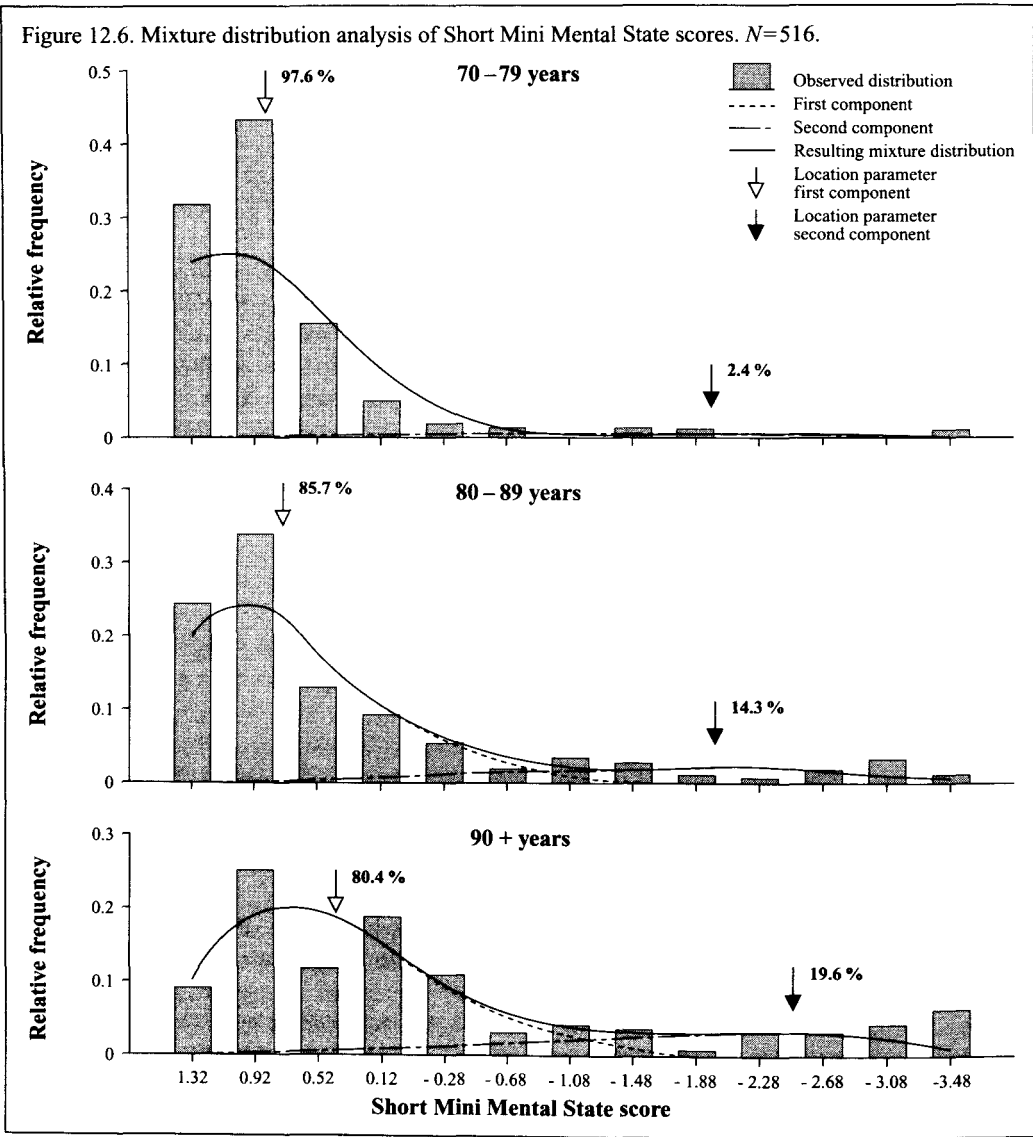


specificity. The observation that this impairment increases with disease severity is consistent with previous studies (Bäckman, Josephsson, Herlitz, Stigsdottir, & Viitanen, 1991; Herlitz, Adolfsson, Bäckman, & Nilsson, 1991).

4.3 Mixture Distribution Analysis

The observed differences in performance profiles between persons with and without a diagnosis of dementia raise the question of whether measures closely associated with that diagnosis have a bimodal distribution. The SMMS (Klein et al., 1985), which is often used to screen for dementia in random samples of older adults, is well suited to examine this issue. According to the mixture-distribution view, the total distribution of scores on the SMMS is made up of two different distributions, one for the "normal" (i.e., without dementia) portion of the sample, and the other for the portion with dementia. With increasing age, the central tendency of the distribution representing the portion of the population without dementia is expected to be shifted toward the central tendency of the distribution representing the subpopulation with dementia.

Figure 12.6. Mixture distribution analysis of Short Mini Mental State scores. $N=516$.



Results of a mixture distribution analysis indicate that the frequency distributions of SMMS scores over age are consistent with these predictions (Fig. 12.6; cf. Reischies et al., 1996), and support the claim that normal cognitive aging and aging with dementia are two distinct phenomena (cf. Reischies & Lindenberger, 1995). At the same time, the observed convergence of the two distributions with advancing age indicates that the “signal” of dementia is especially difficult to separate from the “noise” of normal aging in very old age.

5 Discussion

5.1 *Design Limitations of the Present Analyses*

Before concluding, we would like to highlight once more the pitfalls and constraints of cross-sectional studies (P. B. Baltes, Reese, & Nesselroade, 1988; Hertzog, 1996; Lindenberger & Pötter, 1998; cf. P. B. Baltes et al., Chapter 1). With respect to this study, three limitations are especially relevant. First, cross-sectional data sets do not permit direct inferences about intraindividual change and about interindividual differences in intraindividual change. Second, cross-sectional age differences represent complex outcomes of multiple systems of influence and change. In old and very old age, pathological (rather than “normal”) aging processes, selective mortality, and generational cohort effects are all likely to be involved. Third, longitudinal (e.g., life-history) interpretations of cross-sectional age differences are necessarily retrospective in character, and need to be corroborated by converging evidence from other sources.

By now, longitudinal follow-up investigations of the sample reported in this study are under way. In addition, we continuously keep track of the mortality history of the BASE participants. It is hoped that the combined analysis of mortality and longitudinal follow-up information will shed further light on the ways in which intraindividual changes, mortality, and generational differences contribute to the age-related cross-sectional differences observed in this study (cf. Keiding, 1991; Nesselroade, 1991).

5.2 *Summary of Findings*

The purpose of this chapter was to delineate the potentials and limits of intellectual functioning in old and very old age. To this end, we reported the age gradients, structure, and correlates of intellectual abilities in old and very old age as observed in the Intensive Protocol of the first wave of the Berlin Aging Study.

Our main findings can be summarized under the dual headings of *continuity versus discontinuity* and *preserved differentiation versus dedifferentiation*. According to continuity and preserved-differentiation views, intelligence in old and very old age is assumed to be characterized by predictive, functional, and structural continuity to earlier phases of life. In support of this view, we found: (a) that the different intellectual abilities continue to exist as distinct dimensions of interindividual differences at the first-order level; (b) that there is no general tendency toward a decrease in between-person variability; (c) that life-history differences assessed by sociobiographical variables continue to be associated with intelligence in general, and with knowledge, in particular; and (d) that the ability to learn from experience under highly supportive conditions is well preserved into very old age, as suggested by the findings obtained with the ECR test.

In contrast, the discontinuity and dedifferentiation views posit that old-age intelligence is primarily dominated by aging-induced changes in brain integrity. Albeit such changes are probably present throughout ontogeny, their increasing importance with advancing age is assumed to impose a common and general constraint on many different aspects of intellectual functioning, and to transform old-age intelligence into a distinct developmental phenomenon. In agreement with this view, we found: (a) that the age gradients of predominantly mechanic (broad fluid) and predominantly pragmatic (broad crystallized) intellectual abilities converge to yield a picture of generalized linear decre-

Table 12.6. *BASE participants' performance in Memory for Text (percentage of correct answers)*

"Yesterday Peter, who is seven years old, went to Lake Lead for some fishing. He took his dog Prince along. The lake's banks were flooded due to heavy rain during the previous four days. Peter slipped on the muddy ground and fell into the deep water. He would have drowned if his dog had not jumped in after him and helped him to reach the shore again."

	Persons without dementia			Persons with dementia
	70–79 (<i>n</i> = 164)	80–89 (<i>n</i> = 138)	90+ (<i>n</i> = 105)	<i>M</i> = 90.8 years (<i>n</i> = 106)
What was the boy's name?	79.3	81.9	70.5	41.3
How old was the boy?	63.4	55.8	52.4	34.9
What was the dog's name?	31.1	26.8	9.5	1.8
What was the lake called?	42.7	26.1	12.4	7.3
Why did the boy fall into the lake? ^a	84.8	81.9	70.5	46.8

Note. One of the six questions ("What is the main episode of the story?") is not presented in the table.
^aThe answer was judged as correct if at least one of the following reasons were mentioned: (a) because he slipped; (b) because it was muddy; (c) because the lake's banks were flooded.

ment (directionality dedifferentiation); (b) that this picture applies to samples both above and below the average on sociobiographical life history variables; (c) that the intercorrelations among intellectual abilities are of greater magnitude and uniformity than commonly observed during earlier phases of life, and are well described by a single factor of general intelligence; and (d) that sensory and sensorimotor variables in combination share about 59% of their total reliable variance with the general factor of intelligence (cf. P. B. Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1997). In addition, the results obtained with the ECR test demonstrate that the ability to learn from experience is severely compromised in individuals with dementia.

To provide an illustration of the average and the range of intellectual functioning in this heterogeneous sample of old and very old individuals, Table 12.6 contains the item-by-item report for one of the three memory tests of the psychometric test battery. In this test, a story about a boy who went fishing, slipped into the water, and was saved by his dog, was presented in large fonts on the computer screen, and read aloud by the research assistant. Immediately thereafter, participants were asked questions about the content of the story. As shown in the table, more than 70% of the individuals without dementia in each of the three age groups (70–79, 80–89, and 90+ years) remembered the name of the boy, and the reason why he had slipped into the water. In contrast, the age of the boy, the name of the dog, and the name of the lake were less likely to be remembered.

5.3 *Outlook: Exploring the Systemic Significance of Intellectual Functioning in Old and Very Old Age*

Taken together, the findings reported in this chapter lend support to the theoretical position that cognitive aging is a relatively unitary and general process, at least

within the age period of old and very old age (cf. Li & Lindenberger, in press; Salthouse, 1996). However, in light of the interpretational ambiguity associated with cross-sectional, correlational data (Hertzog, 1996; Lindenberger & Pötter, 1998), additional evidence based on other methods, such as longitudinal, experimental, and simulation designs, is needed to examine further the tenability of this position.

Given their pervasiveness and magnitude, the age-based decrements in intellectual functioning observed in this sample of old and very old individuals are likely to constrain functioning in other domains such as social relations or everyday competence. Other analyses within BASE support this contention (Staudinger et al., Chapter 11; M. M. Baltes et al., Chapter 14; Smith et al., Chapter 17; cf. Reischies & Lindenberger, 1996). According to one interpretation (P. B. Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994b), the general tendency of intelligence in old age to relate to numerous psychological, social, and behavioral dimensions may reflect the dependency of one's inner, social, and physical life on some minimum amount of intellectual capacity. To complicate matters, this minimum amount is likely to vary as a function of both sampled task difficulty within and across domains and of interindividual differences in intelligence-extraneous resources. Thus, cross-sectional interindividual-difference investigations of the kind presented here need to be complemented not only by real-time longitudinal follow-ups, but also by short-term longitudinal, intraindividual investigations (Molenaar, 1994) to understand better the (presumably nonlinear) links between intellectual and other domains of functioning (P. B. Baltes et al., 1988; Kruse, Lindenberger, & Baltes, 1993; Lindenberger & Baltes, 1995b).

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