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Cross-Sectional and Longitudinal Patterns of Dedifferentiation in Late-Life Cognitive and Sensory Function: The Effects of Age, Ability, Attrition, and Occasion of Measurement

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The dedifferentiation hypothesis is examined with respect to age-group differences, ability-group differences, attrition-group differences, and time. Cognitive and sensory data were analyzed from individuals ($n = 1{,}823$) who completed a clinical assessment on at least 1 of 3 occasions of measurement in the Australian Longitudinal Study of Ageing. Inconsistent dedifferentiation effects were associated with low ability and early attrition from the study, but age-related dedifferentiation was not found. Longitudinal analyses confirmed the cross-sectional analyses. Even though instances of dedifferentiation were identified between pairs of sensory and cognitive variables, consistent patterns of dedifferentiation were not found. These results do not support the view that shared biological factors become increasingly important for explaining within-individual change in cognitive and sensory function in later life.

An unresolved issue in intelligence research concerns whether cognitive abilities become more differentiated as children develop into adults and less differentiated as adults age. Theories of factor differentiation have existed since 1927, when Spearman proposed his theory of general intelligence (*g*) and postulated that the factor structure among cognitive abilities varies with age (Spearman, 1927). Theories exist both for differentiation of abilities from childhood to adolescence (Garrett, 1938) and for dedifferentiation of abilities in old age (Balinsky, 1941). Differentiation and dedifferentiation describe patterns of decreasing between-individual correlations among cognitive abilities during childhood and later increases in correlations among abilities in late adulthood. However, there is a lack of clarity in the literature about what constitutes a significant or meaningful increase or decrease in correlations among abilities. Although theories of dedifferentiation refer to patterns of development over time, most research in this field has been cross-sectional. Inferences about within-individual cognitive change have been made on the basis of age differences in the structure of cognitive abilities (Hofer & Sliwinski, 2001).

There are varying degrees of possible differentiation among cognitive abilities. Strong differentiation involves the emergence of new cognitive factors from a more general factor. In late adulthood, strong dedifferentiation would imply changes in the factor structure to a reduced number of cognitive factors. A weak interpretation of age differentiation would involve a significant increase in shared variance among cognitive factors. In most studies of dedifferentiation reported in the aging literature, authors refer to weak dedifferentiation and compare the magnitude of associations among cognitive factors rather than reporting the complete loss or gain of factors (Cunningham & Birren, 1980).

Empirical support for the changing patterns of differentiation among cognitive abilities has been mixed. In an early review of the literature, Anastasi (1970) concluded that there was evidence of differentiation from early childhood to adolescence. Likewise, some life span and aging studies have also shown evidence of dedifferentiation (Baltes, Cornelius, Spiro, Nesselroade, & Willis, 1980; Cornelius, Willis, Nesselroade, & Baltes, 1983; Green & Berkowitz, 1964; McHugh & Owens, 1954), whereas others have shown increased differentiation in old age (Cunningham, Clayton, & Overton, 1975; Foulds & Raven, 1948). Reinert (1970), in his review, found mixed evidence for differentiation and dedifferentiation over the life span. Carroll's (1993) reanalysis of data sets

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did not find support for life span changes in differentiation. Recently, some authors have failed to find either differentiation or dedifferentiation among cognitive abilities over the life span (Bickley, Keith, & Wolfe, 1995; Deary et al., 1996; Juan-Espinosa, Garcia, Colom, & Abad, 2000; Park et al., 2002), whereas others have found mild dedifferentiation among older adults (Mitrushina & Satz, 1991).

An elaboration of differentiation theory described as the *ability-differentiation hypothesis* by Reinert, Baltes, and Schmidt (1965) proposes that the factor structure among intellectual abilities differs according to level of intellectual ability. If samples are stratified by ability, lower levels of ability are associated with less differentiation. More consistent findings of dedifferentiation have resulted from using (a) samples stratified by ability levels and not age and (b) large samples. For example, Deary et al. (1996) found that cognitive abilities had stronger associations with Spearman's *g* for lower ability children aged 14 to 17 years in a sample of 10,500.

In the area of cognitive aging, there is renewed interest in the issue of dedifferentiation because of the well-replicated finding of large covariation among cognitive and sensory factors in cross-sectional studies spanning large age ranges. These findings have also been interpreted to support a common factor theory, if not a common cause (Anstey, 1999; Anstey & Smith, 1999; Anstey, Stankov, & Lord, 1993; Baltes & Lindenberger, 1997; Christensen, Mackinnon, Korten, & Jorm, 2001; Lindenberger & Baltes, 1994). Common factor theories have given rise to theoretical questions similar to those proposed by Spearman's *g* (e.g., Lindenberger & Baltes, 1994; Luszcz & Bryan, 1999; Salthouse, 1996a, 1996b), including whether a single general factor underlies cognitive decline, whether general plus specific factors underlie cognitive decline, or whether specific factors have the same general effect on cognition over the life span (e.g., Allen et al., 2001; Anstey, Luszcz, & Sanchez, 2001a; Christensen et al., 2001; Hofer, Berg, & Era, 2003; Park et al., 2002). Explanations for the factors influencing cognitive decline include genetic factors, neurochemical factors (e.g., catecholaminergic functions in the brain), and central nervous system efficiency and integrity (e.g., Anstey, Lord, & Williams, 1997; Anstey & Smith, 1999; S.-C. Li & Lindenberger, 1999; S.-C. Li, 2002). A further caveat to the debate about common factors emergent in cognitive aging studies arises from methodological critiques of cross-sectional designs using large age ranges as a basis for making inferences about aging processes. Hofer and Sliwinski (2001) and Hofer, Sliwinski, and Flaherty (2002) demonstrated that some of the commonality among cognitive factors evidenced in cross-sectional studies is confounded by mean trends.

Recent work also reveals a diversity in the nature of relationships among cognitive and sensory abilities in late life that is often overlooked when global explanations relating to common factor models are discussed. Anstey, Luszcz, and Sanchez (2001b) reported an association between marked visual decline and memory decline over 2 years but no association between marked declines in vision and speed, hearing and memory, or hearing and speed. In a cross-sectional study, Anstey, Dain, Andrews, and Drobny (2002) compared the extent to which visual acuity and color vision explained age differences in face recognition, fluid intelligence, and Stroop test performance. They found a different pattern of results for the association of age and visual abilities with all three cognitive factors. Studies such as these suggest that generalizations about the association between cognitive and sensory function are inappropriate and a more complex account of sensory–cognitive relations is required. An alternative but rarely debated possibility is that disorganization increases among cognitive abilities in aging as differential neurophysiological systems age at different rates (Fozard, Metter, & Brant, 1990). This could lead to increased differentiation among cognitive abilities or dedifferentiation among groups of similar abilities but not between different ability domains.

The present study is unique in that the issue of dedifferentiation is examined among both cognitive and sensory factors, longitudinally and cross-sectionally. This enables an evaluation of whether the phenomenon of dedifferentiation is specific to cognition or whether it occurs among cross-domain associations. If common factors underlie cognitive and sensory aging, cross-domain dedifferentiation would be expected. Dedifferentiation may occur because of the increasing influence of biological aging processes. Individuals who do not persist in longitudinal studies are usually older and of lower ability, and they are also more likely to be in a state of functional decline (Anstey & Luszcz, 2002; Anstey, Luszcz, Giles, & Andrews, 2001; Lindenberger, Singer, & Baltes, 2002). Attrition from the study is therefore expected to be associated with increased dedifferentiation of cognitive and sensory abilities.

Most accounts of dedifferentiation have relied on the visual inspection of correlation matrices to determine if the size of correlations among cognitive factors increases according to age or ability. Few studies have provided actual statistical tests of the difference in magnitude of correlations. This is particularly problematic when studies have small, unrepresentative samples and no consideration is given to the standard error of measurement of the correlations being examined. Also lacking has been discussion of what constitutes a substantively meaningful increase in the association between cognitive factors in studies of cognitive dedifferentiation. In the present study, we aim to provide quantitative comparisons of dedifferentiation in the very old by establishing some benchmarks for what can be considered small, moderate, or large increases in the size of correlations among factor pairs between groups or over time.

Another limitation of previous research on dedifferentiation is the lack of consideration of variables that potentially confound the associations among cognitive factors or cognitive and sensory factors, such as health, education, and age. These confounding variables may contribute to the correlations observed within groups while confounding between-group comparisons (Hofer et al., 2003; Hofer, Sliwinski, & Flaherty, 2002). Normal aging is associated with cognitive decline, and this has the implication that when researchers study dedifferentiation according to age, they are also studying dedifferentiation according to ability. Furthermore, results are affected by sampling bias resulting from nonrandom selection and, in longitudinal studies, the compounding problem of sample attrition. In a longitudinal study, the problem of maintaining representative samples increases with the duration of the study, as higher ability and healthier participants are more likely to persist from wave to wave (Anstey & Luszcz, 2002; Lindenberger et al., 2002). For a true test of dedifferentiation in a cross-sectional

study, the probability of being selected into the sample needs to be the same at each age, and this is impossible in very old age groups where mortality occurs. In longitudinal studies, researchers have the advantage of studying the same individuals on multiple occasions, but their studies suffer from the same selection effects at the beginning of the study as in cross-sectional studies and have the further difficulty of sample attrition not being independent of cognitive performance (Anstey & Luszcz, 2002; Hofer, Sliwinski, & Flaherty, 2002).

In the present study, we examine dedifferentiation from four perspectives within the same sample. These perspectives include age, ability, attrition, and occasion of measurement. Drawing together results in a large, population-based sample of older adults who have been followed longitudinally will provide a more thorough investigation of the issue of dedifferentiation than has been conducted previously. The four perspectives yield four specific hypotheses. First, associations among factors will be larger for older age groups than younger age groups in cross-sectional analyses. Second, associations among factors will be larger in lower ability groups than higher ability groups. Third, associations among abilities will be higher for participants who leave the study earlier. Finally, associations among factors will increase at each occasion of measurement within the same sample. Altogether, the results of this study will clarify conditions under which dedifferentiation in late life is likely to occur and provide an empirical basis for evaluating current theories of cognitive and sensory aging.

Method

Sample and Procedure

The sample was drawn from participants in the Australian Longitudinal Study of Ageing (ALSA; see Luszcz, Bryan, & Kent, 1997, for more details). The South Australian Electoral Roll was used as a sampling frame to identify households with residents over 70 years of age (Hugo, Healy, & Luszcz, 1987). The sample was stratified by age and sex into three 5-year cohorts—70–74 years old, 75–79 years old, and 80–84 years old—and a fourth cohort of individuals older than 85 years of age. Randomly sampled individuals within these cohorts were invited to participate in the ALSA on a voluntary basis; men and those over 85 were oversampled. Coresidents of participants aged 65 to 69 years were also invited to participate, and their data are included in the present study.

The study comprises six waves of data collection: the baseline, which occurred between September 1992 and March 1993, with four subsequent waves at approximately 12-month intervals and a sixth wave that commenced in September 2000. Waves 2, 4, and 5 comprised telephone interviews and did not include a clinical or cognitive assessment; therefore, data from Waves 1, 3, and 6, spanning an 8-year period, are reported.

Data were collected in two phases using two different formats. A comprehensive 2-hr home interview was followed by an individual clinical assessment conducted approximately 2 weeks later. The home interviews yielded demographic data and self-reported or subjective descriptions of health, depression, medical conditions, cognitive status, and memory, as well as subjective measures of vision, audition, and physical function. Individual clinical assessments provided objective cognitive and sensory data, using neuropsychological tests and standard functional assessments.

At Wave 1, 2,087 participants (1,056 men) were interviewed and 1,620 or 77% (843 men) underwent the clinical assessment. At Wave 3, 1,679 participants (824 men) were interviewed and 1,423 or 85% (707 men) underwent the clinical assessment. At Wave 6, 791 participants (334 men) were interviewed and 525 or 70% (223 men) underwent the clinical assessment. The subset of data analyzed for the present study is drawn from participants with a clinical assessment at Wave 1, Wave 3, or Wave 6. This yielded a total sample of 1,823 or 83% of the baseline sample. Figure 1 shows the numbers of participants at Wave 1, Wave 3, and Wave 6 in terms of whether or not they completed the clinical assessment. Descriptive statistics and results of change over the first 2-year period of the study for the variables included in the present study are available in Luszcz (1998).

Background Variables

Self-rated health (SRH) was measured on a 5-point Likert scale ranging from 1 (*excellent*) through 5 (*poor*). *Number of conditions* (MedCon) was the total number of chronic and acute health conditions experienced by the participant out of a total of 61 listed on the health questionnaire. The *Center for Epidemiologic Studies Depression Scale* (CES-D) was used to measure level of depressive symptoms (Radloff, 1977). *Total years of formal education* (hereinafter referred to as education) was used as an index of education.

Measures of Cognitive Function

For longitudinal analyses, selection of measures was restricted to those for which data were collected at Waves 1, 3, and 6 because these waves included a clinical assessment. These measures have been described in detail previously (Anstey et al., 2001a; Luszcz, 1998; Luszcz et al., 1997). Measures described below are grouped according to the latent variables used in the statistical analyses.

Processing Speed

The *Digit Symbol subscale* (DSS) of the Wechsler Adult Intelligence Scale—Revised (WAIS–R; Wechsler, 1981) was used to assess processing speed. The participant was required to substitute symbols corresponding to the numbers 1 through 9 into a randomly ordered array of 93 digits. The number correctly substituted in 90 s was analyzed.

Verbal Ability

Three items from the *Similarities* subscale of the WAIS–R (Wechsler, 1981) assessed verbal reasoning. *Picture naming* was measured with a short form of the Boston Naming Test (Mack, Freed, Williams, & Henderson, 1992). The *National Adult Reading Test* (NART; Nelson, 1982) was used to measure verbal knowledge as an element of crystallized ability. It comprises 50 infrequently used words of irregular pronunciation that respondents are asked to read aloud.

Memory

Symbol recall. The DSS of the WAIS–R (Wechsler, 1981) also provided a basis for incidental symbol memory. Participants were required to complete all 93 substitutions to equate exposure to the stimuli. On completion of the DSS, participants were given a symbol recall sheet with the numbers 1 through 9 but without the corresponding symbols and asked to draw as many of the symbols as they could remember matched with each number.

Picture recall. The Boston Naming Test also provided a basis for incidental picture recall. Participants were asked (without prior warning) to recall the 15 pictures they had seen immediately after the test.

Word recall. The three word-recall items from the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) were summed to create a word-recall measure (*MMRecall*). Each word correctly recalled was scored as 1, yielding a total possible score of 3.

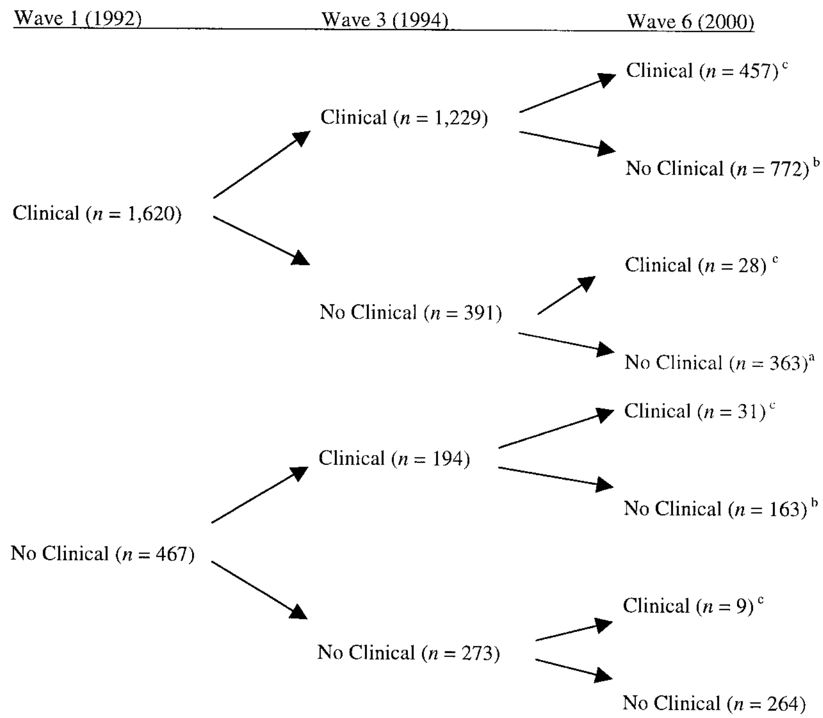

Figure 1. Number of participants at each wave completing clinical and nonclinical components of assessment. [a]Sum to form W1Clin (n = 363), that is, clinical data at Wave 1 only. [b]Sum to form W3Clin (n = 935), that is, clinical data at Wave 3 but not Wave 6. [c]Sum to form W6Clin (n = 525), that is, clinical data at Wave 6.

Vision

Corrected distance visual acuity was measured at 3 m for each eye using a well-illuminated Snellen chart. For structural equation modeling, the logarithms of the minimum visual angles resolvable in the left and right eyes were used as indicators of a latent variable called *vision* (Anstey et al., 2001a). The third indicator of the latent variable vision was *near visual acuity* (nearvis). This was measured at 20 cm using a chart containing short passages of text printed using font sizes ascending from 5 to 18 points. The left eye and right eye were tested separately and the score was the smallest font read. The score of the better eye was used.

Hearing

Portable audiometers with standard earphones were used to conduct pure tone threshold testing. The participant was initially asked whether he or she had a better ear; if so, testing began with that ear. Otherwise, testing began with the right ear. The lesser threshold at 2.0, 3.0, and 4.0 kHz for either the left or right ear (generating three threshold values) was used as an indicator of the latent variable *hearing*. These frequencies were chosen because they had minimal missing data at Wave 1 due to hearing impairment and therefore allowed for observation of change over the 8-year follow-up period (Anstey, Luszcz, & Sanchez, 2001a).

Statistical Analysis

The general approach taken to evaluate dedifferentiation was to compare the correlations between pairs of factors within age groups, ability groups, attrition groups, and occasions of measurement. Factors were covaried, and potentially confounding variables were partialed from the associations among factors. All cognitive and sensory variables were standardized prior to analysis to a common metric (M = 5.0, SD = 1.0) across occasions. This retained the relative metric both between and within individuals. Prior to describing the statistical modeling in detail, we must describe the methods used for dealing with missing data and the assumptions of factorial invariance that are made when comparing groups on a given factor structure among abilities.

Treatment of Missing Data

Missing data due to sample attrition across time were handled using likelihood-based statistical methods available in the AMOS structural equation modeling program (Arbuckle & Wothke, 1999). Likelihood-based approaches are regarded as standard procedure for obtaining less biased population estimates under conditions of nonparticipation and when there are few instances of missing data (Schafer, 1997). This method maximizes the casewise likelihood and therefore uses all available information within and across occasions of measurement. Valid inferences can be drawn from analyses of longitudinal data involving missingness if the missing data mechanism has been measured and included in the appropriate analysis. Under these conditions, known as missing at random, parameter estimates will be unbiased and efficient (e.g., Diggle & Kenward, 1994; Little & Rubin, 1987). To overcome bias introduced by reasons of attrition and to include information on factors associated with the causes of missing data, we included

background variables previously associated with mortality and attrition in the ALSA (Anstey & Luszcz, 2002; Anstey, Luszcz, Giles, & Andrews, 2001) in all analyses in the present study (see also Hofer et al., 2002). Background variables from Wave 1 including age, sex, education, SRH, MedCon, and CES-D score were covaried with the factor-level constructs. In a longitudinal study involving multiple waves of data, the full-information maximum likelihood technique enables participants to remain in the analyses even when they have not participated in specific waves. This allows individuals within the sample who become deceased during a longitudinal study to be included in longitudinal analyses. This may or may not be desirable, depending on the aims of the research. In the present study, the influence of sample attrition (as a proxy for health-related and mortality influences; e.g., Anstey, Luszcz, Giles, & Andrews, 2001; Sliwinski, Hofer, Hall, Buschke, & Lipton, in press) on dedifferentiation was investigated by comparing attrition-status groups in which length of persistence in the study was used as a basis for classifying participants.

Establishment of Level of Factorial Invariance Between Waves

Factorial invariance refers to the situation where the same observed variables measure the same latent variable at different ages, at different times, or within different samples. Evidence for factorial invariance provides a basis for comparison of a particular construct between groups and between occasions of measurement. Factorial invariance does not imply that different groups have the same mean levels of latent variables being measured. For example, three measures of episodic memory may be shown to measure the latent variable of episodic memory in two different samples, but one sample may have higher mean scores on the measures of episodic memory and a higher latent mean for the latent variable of episodic memory than the other group.

In the present study, we established longitudinal factorial invariance for each cognitive and sensory factor separately, prior to further analyses. This approach was chosen in favor of testing the factorial invariance of a model that included all factors simultaneously because it yields information about specific factors at each level of factorial invariance. Little previous research has been published on the factorial invariance of Vision and Hearing factors in aging.

The method used is described by Meredith (1993) and involves a hierarchy of increasingly stringent constraints (see also Hofer, Horn, & Eber, 1997; Meredith & Horn, 2001; Schaie, Maitland, Willis, & Intrieri, 1998). For a baseline model, configural invariance was evaluated. This model requires only the same number of factors and pattern of salient factor loadings across groups or occasions. The following hierarchy of model constraints for factorial invariance was then evaluated: (a) weak factorial invariance, the condition where factor loadings are constrained to be equal across groups or occasions; (b) strong factorial invariance, where additional equality constraints are placed on the manifest intercept (mean) terms, permitting mean differences to be expressed at the factor level; and (c) strict factorial invariance, in which unique variances are additionally constrained to be equivalent between groups or occasions of measurement. We evaluated factorial invariance while allowing factor variances, covariances, and factor means (other than those required for identification purposes—e.g., with one of the factor means fixed to specify the metric of the latent variables) to be freely estimated.

Goodness of fit for the factorial invariance models was assessed by examining the ratio of the discrepancy function to the degrees of freedom (χ^2/df), the normed fit index (NFI), the nonnormed fit index (NNFI), and the root-mean-square error of approximation (RMSEA; Browne & Cudeck, 1992). Values of χ^2/df below 3 are regarded as acceptable, but values below 2 are desirable (Arbuckle & Wothke, 1999). Values greater than .90 are regarded as acceptable for the NFI and the NNFI. For the RMSEA, values below .08 are regarded as acceptable, but values less than .05 are considered desirable. For the present study, models with an NNFI value greater than .90 and an RMSEA value less than .08 were accepted as having adequate fit.

Testing Dedifferentiation Between Age Groups

The sample was divided into three age groups. Those 65 to 74 years old at Wave 1 were included in the *young-old* group, those 75 to 84 years old at Wave 1 were included in the *mid-old* group, and those 85 to 103 years old at Wave 1 were included in the *old-old* group. Too few older adults were in the 85–94 year-old and 95+ year-old age groups to warrant separating these groups. A multiple-group procedure in AMOS 4.0 (Arbuckle & Wothke, 1999) was used to compare the intercorrelations between factor pairs for each age group. Multiple-group procedures allow one not only to estimate the parameters of the model for each group separately but also to estimate the standard errors of the differences in each parameter between groups. This provides for testing whether parameters are significantly different between groups.

The model tested is shown in Figure 2. Five latent variables per wave (vision, hearing, verbal, speed, and memory) were covaried in a single model to obtain estimates of the factor intercorrelations. Factor variances for the young-old group were fixed at 1.00 to establish the factor metric. Intercepts of observed variables and factor loadings were constrained to be equal between groups. The same model was tested on the cross-sectional data from Wave 1, Wave 3, and Wave 6. For each wave, background variables were first covaried with each factor, and then, in a second analysis, regressed on each factor. This provided estimates of unpartialed and partialed intercorrelations among factors. At Wave 1, the total number of participants in the three age groups was 1,823. At Wave 3, it included the 1,460 participants who completed the clinical assessment (most but not all also did the clinical assessment at Wave 1; see Figure 1). At Wave 6, the total number of participants in the three age groups was 525 (see Table 1).

Testing Dedifferentiation Between Ability Groups

The sample was divided into three ability groups of equal size at Wave 1 based on performance on the DSS. These groups were called the *low-ability*, *mid-ability*, and *high-ability* groups, respectively. The DSS was chosen as the variable for classifying the sample because it was normally distributed, had a larger range of values than the other cognitive measures, and was completed by 1,243 participants at Wave 1. A single measure was chosen to minimize the loss of participants because of missing data. Analy-

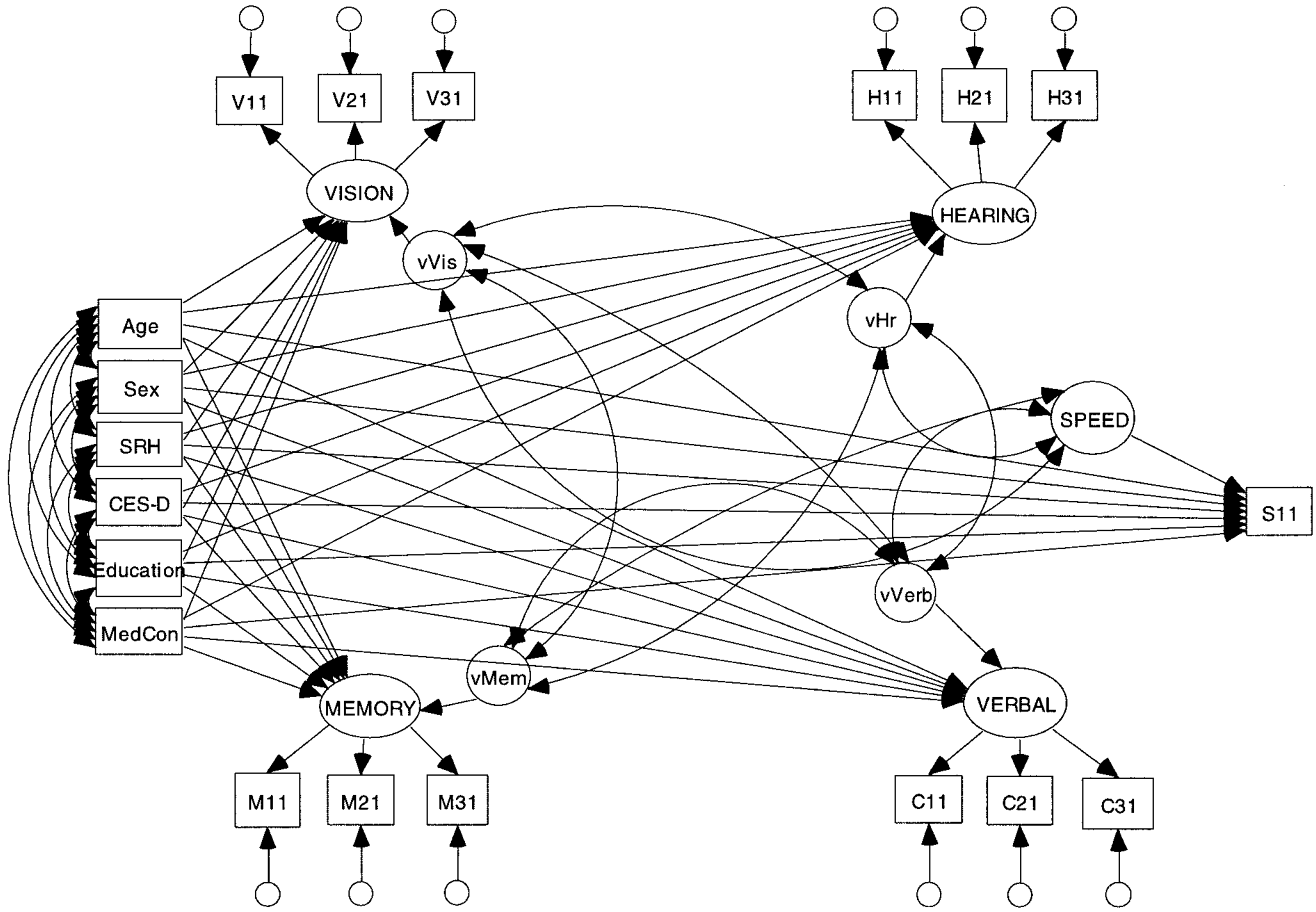

Figure 2. Cross-sectional covariance model used in multiple-group analyses of age, ability, and attrition groups at Wave 1. Cognitive and sensory factors are regressed on background variables. V11 = the logarithm of the minimum visual angle resolvable in the left eye; V21 = near visual acuity; V31 = the logarithm of the minimum visual angle resolvable in the right eye; H11, H21, and H31 = pure tone thresholds at 2, 3, and 4 kHz, respectively; S11 = score on the Digit Symbol subscale of the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981); M11 = symbol recall; M21 = picture recall; M31 = word recall; C11 = similarities; C21 = picture naming; C31 = score on the National Adult Reading Test; vVis, vHr, vMem, and vVerb = variances of Vision, Hearing, Memory, and Verbal factors, respectively; SRH = self-rated health; CES-D = Center for Epidemiologic Studies Depression Scale; MedCon = number of medical conditions.

ses of ability dedifferentiation at Wave 1, Wave 3, and Wave 6 were based on participants with DSS data who survived to each wave. At Wave 1, there were 1,243 participants in the analyses (see Table 1); at Wave 3, there were 997 participants (i.e., those who completed the Wave 3 clinical assessment and had DSS data at Wave 1); and at Wave 6, there were 398 participants (i.e., those who completed the clinical assessment at Wave 6 and had DSS data at Wave 1). We chose not to impute Wave 1 DSS scores for the 621 participants for whom data on the DSS were missing at Wave 1, to avoid double imputation of cognitive data for these participants (once at classification and once at the modeling stage). Numerous studies have shown that the DSS is a valid indicator of general cognitive ability and is sensitive to age differences in later life (e.g., Salthouse, 1991, 1992).

A specific problem confronted in ability analyses in a longitudinal study is that lower ability is associated with attrition, so more missing data occur in groups with participants of lower ability, as has been demonstrated in the ALSA sample (Anstey & Luszcz, 2002). The approach taken here was to conduct analyses separately for each wave, including only the sample persisting to that wave. This resulted in proportionately more participants in the high-ability groups at later waves. A proportion of these participants had missing data on either one, some, or all cognitive data for a given wave. There were 363 participants in the group who only completed the Wave 1 clinical assessment (W1Clin). W1Clin included participants who completed the clinical assessment at Wave 1 only, that is, they did not complete further clinical assessments. At Wave 3, 935 participants completed the Wave 3 clinical assessment (W3Clin). W3Clin included participants who completed the clinical assessment at Wave 3 but not at Wave 6; most but not all of these participants completed the clinical assessment at Wave 1 (see Figure 1). At Wave 6, 525 participants completed the clinical

Table 1
Cross-Tabulation of Wave 1 Age Groups by Ability and Attrition Groups

Group	65–74 years	75–84 years	85+ years	Total
		Ability group		
Low ability	88	208	144	440
Mid-ability	135	185	41	361
High ability	238	185	19	442
Total	461	578	204	1,243
		Attrition group		
W1Clin	93	160	110	363
W3Clin	271	460	204	935
W6Clin	282	214	29	525
Total	646	834	343	1,823

Note. W1Clin = sample whose members only participated in the clinical assessment at Wave 1; W3Clin = sample whose members participated in the clinical assessment at Wave 3 but not Wave 6; W6Clin = sample whose members participated in the clinical assessment at Wave 6.

assessment (W6Clin). W6Clin included participants who completed the clinical assessment at Wave 6, but note that some participants who completed the clinical assessment at Wave 6 had missed earlier assessments (see Figure 1). The multiple-group model used for the ability analyses was identical to the one used in the age-group analyses except that groups were classified by ability and not age.

Testing Dedifferentiation Between Groups Based on Attrition Status

The sample was also divided into three groups according to attrition status, and multiple-group analyses were conducted to determine whether dedifferentiation was associated with attrition. Using the method described above, we calculated intercorrelations among factors in AMOS 4.0 (Arbuckle & Wothke, 1999) for each group at Wave 1 and for W3Clin and W6Clin groups at Wave 3. Both unpartialed and partialed estimates were obtained. The multiple-group model used for the attrition-group analyses was identical to the one used in the age-group analyses except that groups were classified by attrition status and not age.

Longitudinal Dedifferentiation

To gain an overall picture of dedifferentiation longitudinally, we conducted an analysis over three waves, in which all factors were covaried. This analysis was conducted separately for the young-old and mid-old and the mid-ability and high-ability groups of individuals who survived to Wave 6 (i.e., who were included in W6Clin). Conducting longitudinal analyses on these subsamples allowed an evaluation of whether longitudinal dedifferentiation was stronger in the mid-old group compared with the young-old group and in the mid-ability group compared with the high-ability group as would be expected according to the dedifferentiation hypothesis. There were too few participants in the old-old and low-ability groups in W6Clin to enable analyses of these groups. The limitation of this approach was the small sample sizes used in each model in relation to the number of variables and parameters in the longitudinal models. The longitudinal model was also estimated for the full W6Clin subsample ($n = 525$).

In the longitudinal models, all factor variances and means were fixed at 1.0 at Wave 1 to set the metric, and factor loadings (except nearvis at Wave 3, which was freed to achieve partial invariance as reported in the Results section) and intercepts were constrained to be equal across occasions of measurement. The cognitive and sensory factors from Waves 1, 3, and 6 were allowed to covary, and the effects of the background variables were partialed. The final model tested is shown in Figure 3, except that the paths from the background variables to the factors representing regression coefficients are not shown. Initially, the model was run with the Verbal factors allowed to covary with all other cognitive and sensory factors; however, this model generated a nonpositive definite covariance matrix. Verbal was henceforth excluded from the longitudinal model, consistent with previous longitudinal models based on this and similar data sets (Anstey, Hofer, & Luszcz, in press; Hofer, Christensen, et al., 2002).

Testing the Difference in Sizes of Correlations Between Groups

We compared correlations between age groups and ability groups using the test of critical ratio of differences (Arbuckle & Wothke, 1999) to obtain a statistical significance test of the difference between the sizes of the correlations. The critical ratio is the difference between two parameters (in this case, correlations) divided by the standard error of the difference, which produces a standard normal distribution.

Evaluating the Substantive Importance of Dedifferentiation Among Factors

In this study, we propose benchmark values to classify differences in variance shared between factors as small, moderate, or large. For a difference between correlations to be regarded as small, we propose that the difference between the squares of the two correlations in question be 5% to 10%. We propose a moderate difference to be 11% to 20% and a large difference to be greater than 20%. For example, if two factors correlated .16 in the young-old group and .40 in the old-old group, the difference would be $.40^2 - .16^2 = .134$, so this difference would be considered of moderate size.

Results

Establishing Factorial Invariance of Cognitive and Sensory Factors as a Prerequisite for Dedifferentiation Analyses

Factorial invariance over the three occasions of measurement (1992, 1994, 2000) was analyzed separately for Verbal, Memory, Vision, and Hearing factors. Goodness of fit statistics for the different levels of invariance are shown in Table 2. Weak factorial invariance was obtained for the Verbal factor, $\chi^2(80, N = 1{,}823) =$

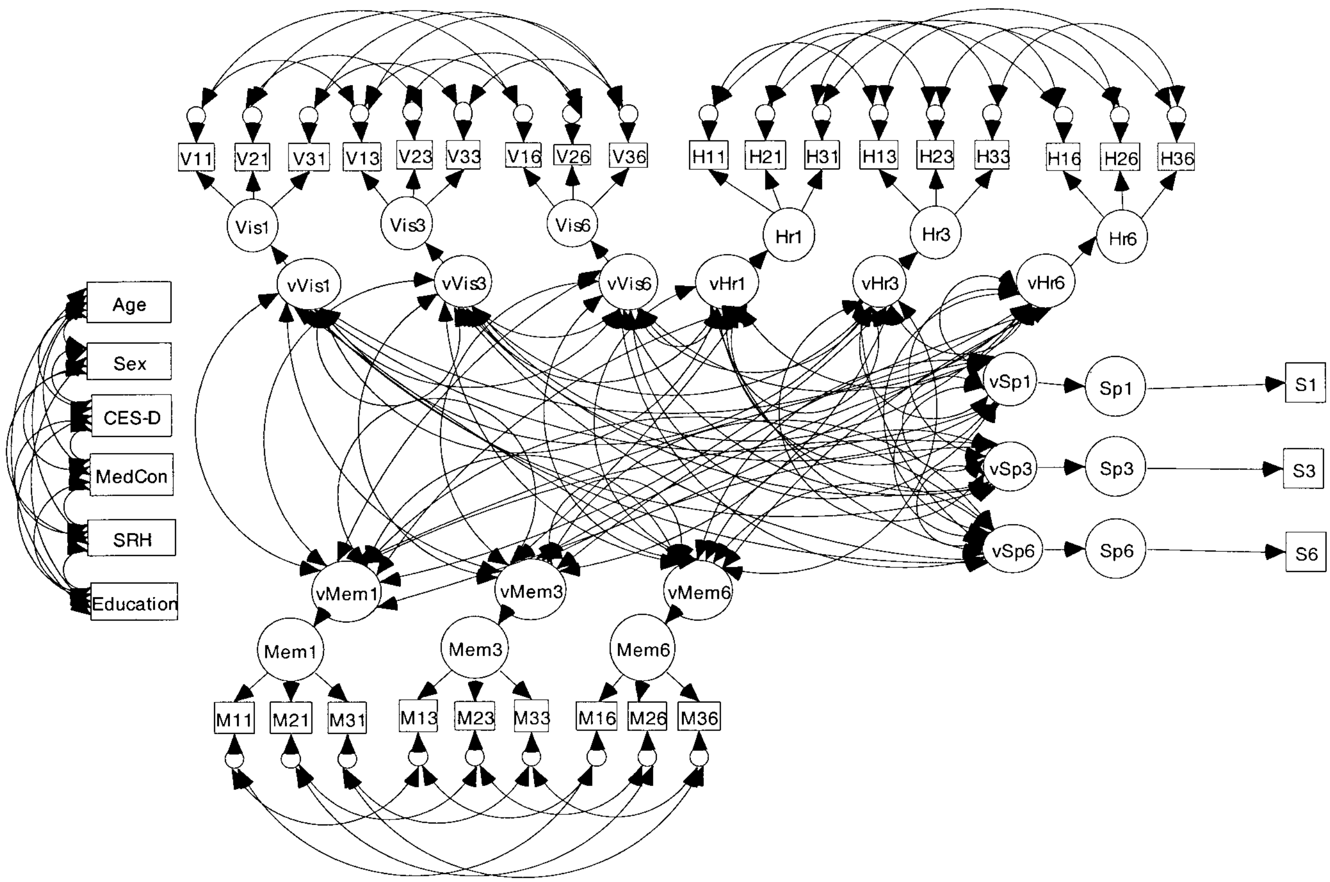

Figure 3. Longitudinal covariance model. Regression paths from background variables to factors were removed to improve visibility of the covariance model. V11, V13, and V16 = the logarithm of the minimum visual angle resolvable in the left eye at Waves 1, 3, and 6, respectively; V21, V23, and V26 = near visual acuity at Waves 1, 3, and 6, respectively; V31, V33, and V36 = the logarithm of the minimum visual angle resolvable in the right eye at Waves 1, 3, and 6, respectively; Vis1 = Vision at Wave 1; Vis3 = Vision at Wave 3; Vis6 = Vision at Wave 6; H11, H13, and H16 = pure tone threshold at 2 kHz at Waves 1, 3, and 6, respectively; H21, H23, and H26 = pure tone threshold at 3 kHz at Waves 1, 3, and 6, respectively; H31, H33, and H36 = pure tone threshold at 4 kHz at Waves 1, 3, and 6, respectively; Hr1 = Hearing at Wave 1; Hr3 = Hearing at Wave 3; Hr6 = Hearing at Wave 6; S1, S3, and S6 = score on the Digit Symbol subscale of the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981) at Waves 1, 3, and 6, respectively; Sp1 = Speed at Wave 1; Sp3 = Speed at Wave 3; Sp6 = Speed at Wave 6; M11, M13, and M16 = symbol recall at Waves 1, 3, and 6, respectively; M21, M23, and M26 = picture recall at Waves 1, 3, and 6, respectively; M31, M33, and M36 = word recall at Waves 1, 3, and 6, respectively; Mem1 = Memory at Wave 1; Mem3 = Memory at Wave 3; Mem6 = Memory at Wave 6; vVis1, vVis3, and Vvis6 = variances of Vision at Waves 1, 3, and 6, respectively; vHr1, vHr3, and vHr6 = variances of Hearing at Waves 1, 3, and 6, respectively; vSp1, vSp3, and vSp6 = variances of Speed at Waves 1, 3, and 6, respectively; vMem1, vMem3, and vMem6 = variances of Memory at Waves 1, 3, and 6, respectively; SRH = self-rated health; CES-D = Center for Epidemiologic Studies Depression Scale; MedCon = number of medical conditions.

314.86, NNFI = .91, RMSEA = .05, but strict factorial invariance had barely adequate fit, $\chi^2(70, N = 1{,}823) = 546.69$, NNFI = .85, RMSEA = .06. Review of the hierarchy of increasingly stringent constraints on the Memory factor shows that even the conditions of strict factorial invariance could be applied while retaining excellent model fit, $\chi^2(70, N = 1{,}823) = 153.70$, NNFI = .95, RMSEA = .03. For the Vision factor at Wave 1, Wave 3, and Wave 6, the weak factorial invariant model had adequate fit, but the strong invariance model had an NNFI of .82. Review of the pattern of means of the three indicators over the three waves showed that maximum likelihood mean estimates for nearvis were higher (indicating worse performance) at Wave 3 than Wave 6, a pattern that was inconsistent with the distance vision measures. The loadings of nearvis at Wave 1 and Wave 6 were constrained to be equal, but the loading at Wave 3 was freed, increasing the degrees of freedom by 1. With this minor change, the partial strong

Table 2
Fit Statistics for Hierarchical Analyses of Factorial Invariance (N = 1,823)

Factor	NPAR	χ^2	*df*	NFI	NNFI	RMSEA
Verbal						
Configural	84	299.75	51	.95	.90	.05
Weak	80	314.86	55	.94	.91	.05
Strong	76	486.59	59	.91	.86	.06
Strict	70	546.69	65	.90	.85	.06
Independence	30	5,471.22	105			
Memory						
Configural	84	74.89	51	.98	.98	.02
Weak	80	78.44	55	.98	.99	.02
Strong	76	102.38	59	.97	.98	.02
Strict	70	153.70	65	.95	.95	.03
Independence	30	3,267.30	105			
Vision						
Configural	84	88.90	51	.97	.98	.02
Weak	80	180.43	55	.95	.93	.04
Strong	76	390.67	58	.89	.82	.06
Partial strong (free nearvis)	77	228.92	64	.94	.92	.04
Strict	70	592.32	59	.83	.72	.07
Partial strict (free nearvis)	71	432.12	65	.88	.82	.06
Independence	30	3,536.80	105			
Hearing						
Configural	81	407.35	51	.97	.94	.06
Weak	77	445.54	55	.96	.94	.06
Strong	73	562.02	59	.95	.93	.07
Strict	77	1,041.14	65	.91	.87	.09
Independence	30	12,162.76	105			

Note. NPAR = number of parameters in the model; NFI = normed fit index; NNFI = nonnormed fit index; RMSEA = root-mean-square error of approximation; nearvis = near visual acuity.

invariance model fit the data at an acceptable level, whereas the partial strict invariance model was only marginally acceptable, $\chi^2(77, N = 1{,}823) = 432.12$, NNFI = .82, RMSEA = .06. An acceptable level of fit for strong invariance was also achieved for the Hearing factor, $\chi^2(73, N = 1{,}823) = 562.02$, NNFI = .93, RMSEA = .07. The level of invariance achieved for each factor was maintained for subsequent analyses of factor intercorrelations. Previous studies have shown it is possible to measure latent cognitive abilities longitudinally (Maitland, Intrieri, Schaie, & Willis, 2000; Schaie et al., 1998), and the results of the present study show it is also possible to measure latent sensory abilities longitudinally.

Stratification of the Sample According to Age Group, Ability Group, and Attrition Group

For the results that follow, the sample was stratified according to age groups, ability groups, and attrition groups. Table 1 shows the numbers of participants in each group at Wave 1. Analyses of age groups and attrition groups were based on the full sample of 1,823 participants, whereas the analysis of the ability groups was based on those with complete DSS data at Wave 1 ($n = 1{,}243$). The old-old age group was overrepresented in the low-ability group, $\chi^2(4, N = 1{,}243) = 192.57$, $p < .01$, and the W1Clin group, $\chi^2(4, N = 1{,}823) = 165.07$, $p < .01$.

Patterns of Dedifferentiation According to Age Groups

Table 3 shows the factor intercorrelations at Waves 1, 3, and 6 for each age group. These results were estimated cross-sectionally using multiple-group analyses in AMOS 4.0 (Arbuckle & Wothke, 1999; see Figure 2). Analyses at Wave 3 and Wave 6 were conducted on subsamples of participants who participated in the Wave 3 and Wave 6 clinical assessments, respectively. Correlations that differ in size are indicated; however, the statistical significance tests do not take into account the direction of the difference in size. For dedifferentiation to occur in the expected direction, an increase in the size of correlations from the young-old to old-old groups is expected. Both unpartialed analyses and partialed analyses are reported.

In the unpartialed analyses at Wave 1, there were significant increases between the young-old and mid-old groups in the strength of association between Vision and Hearing and Vision and Speed. There were significant increases in association between the young-old and old-old groups for Vision and Verbal and Memory and Verbal. There was also a stronger association between Memory and Verbal in the old-old group compared with the mid-old group. In the adjusted analysis, there was no evidence of dedifferentiation, with the few significant differences in size of correlations between groups being in the unexpected direction (i.e., associations among factors were smaller in the old-old groups than in the mid-old and young-old groups). The size of associations was a little smaller in the adjusted analyses.

In the unpartialed analyses of Wave 3, a pattern of dedifferentiation was only evident between age groups for the association between Memory and Verbal, and there were significant differences for Hearing and Speed, Hearing and Memory, and Hearing and Verbal in the unexpected direction. We observed patterns of dedifferentiation for Vision and Speed and Vision and Memory, but these were not significant.

At Wave 6, there was no evidence of dedifferentiation between the young-old and the mid-old groups. The effect sizes for dedifferentiation in the unpartialed analyses at Wave 1 were small, with an increase of 2.5% to 7.9% in shared variance between factors. Overall, there were 4/80 significant age dedifferentiation effects and 10/80 significant effects in the unexpected direction found in the unpartialed analyses. In the partialed analyses, there was 1/80 significant dedifferentiation effect and 5/80 significant effects in the unexpected direction. Overall, these results do not support the age-dedifferentiation hypothesis.

Patterns of Dedifferentiation According to Ability Groups

Table 4 shows the factor intercorrelations for the three ability groups for Waves 1, 3, and 6. These groups were determined on the basis of DSS scores at Wave 1, and participants without DSS data at Wave 1 were excluded. For Wave 3 and Wave 6, analyses were conducted on subsamples of participants who had completed the Wave 3 and Wave 6 clinical assessments, respectively. For dedifferentiation to be present, we would expect a pattern of high to low correlations corresponding with low- to high-ability groups.

In the unpartialed analyses at Wave 1, the correlations between Vision and Speed, Vision and Memory, and Vision and Verbal

Table 3
Intercorrelations Between Pairs of Factors by Age Group

Factor pair	FIML estimates of intercorrelations							
	Unpartialed estimates				Partialed estimates			
	Young-old	Mid-old	Old-old	Sig. diff.	Young-old	Mid-old	Old-old	Sig. diff.
Wave 1								
n	646	834	343		646	834	343	
Vision, Hearing	.02	.16	.01	A*	.01	.15	.04	
Vision, Speed	.19	.34	.32	A*	.18	.27	.33	
Vision, Memory	.13	.31	.01	C**	.09	.26	.07	C**
Vision, Verbal	.17	.35	.24	B**	.14	.30	.21	
Hearing, Speed	.07	.18	.11		.03	.12	.07	
Hearing, Memory	.25	.23	.07	B**, C**	.15	.17	.07	B**, C**
Hearing, Verbal	.22	.19	.14	B**	.22	.17	.06	
Speed, Memory	.56	.60	.63		.50	.55	.56	
Speed, Verbal	.58	.63	.64		.52	.55	.58	
Memory, Verbal	.75	.66	.82	B**, C*	.76	.63	.76	
Wave 3								
n	553	674	233		553	674	233	
Vision, Hearing	.08	.08	.07		.00	.05	.10	
Vision, Speed	.29	.30	.30		.18	.25	.31	
Vision, Memory	.20	.22	.26		.03	.14	.26	
Vision, Verbal	.36	.36	.36		.13	.24	.27	
Hearing, Speed	.20	.20	.05	B*, C*	.08	.12	.05	
Hearing, Memory	.23	.20	.12	B*, C*	.05	.14	.20	C**
Hearing, Verbal	.20	.23	.12	B*	.16	.17	.06	C*
Speed, Memory	.63	.63	.69		.51	.59	.64	
Speed, Verbal	.58	.58	.60		.52	.17	.51	
Memory, Verbal	.67	.68	.89	A*, C**	.86	.64	.92	A**, C**
Wave 6								
n	282	214	29		282	214	29	
Vision, Hearing	.12	.09			.08	.05		
Vision, Speed	.15	.31			.12	.34		
Vision, Memory	.19	.30			.19	.33		
Vision, Verbal	.16	.31			.13	.37		
Hearing, Speed	.14	.14			.12	.08		
Hearing, Memory	.13	.22			.09	.15		
Hearing, Verbal	.14	.15			.20	.16		
Speed, Memory	.55	.60			.53	.59		
Speed, Verbal	.64	.71			.66	.69		
Memory, Verbal	.82	.61		A**	.87	.66		A*

Note. FIML = full information maximum likelihood; Sig. diff. = significant difference; A = significant difference in size of correlation between young-old and mid-old; B = significant difference in size of correlation between young-old and old-old; C = significant difference in size of correlation between mid-old and old-old. There were only 29 participants in the 85+ year age group at Wave 6, and this was too few to allow for calculation of reliable values.
* $p < .05$. ** $p < .01$.

were larger in the low- than the high-ability groups. The correlations between Vision and Verbal and Speed and Memory were also higher in the low-ability group than in the mid-ability group. In the adjusted analyses, the correlations between Vision and Speed, Vision and Memory, and Speed and Verbal were higher in the low-ability groups than in the high-ability group. Effect sizes for the unpartialed analyses ranged from 6.75% to 23.00%, and effect sizes for the partialed analyses ranged from 2.87% to 12.22%, indicating that where ability-related dedifferentiation occurred, it was of small to moderate size. However, ability-dedifferentiation was observed for less than half of the correlations at Wave 1.

At Wave 3, significant dedifferentiation effects were only observed in the unpartialed analyses. Low-ability group correlations were larger than mid-ability group correlations for Vision and Speed, Vision and Memory, Vision and Verbal, Hearing and Speed, and Speed and Memory. Low-ability group correlations were larger than high-ability group correlations for Vision and

Table 4
Intercorrelations Between Factors by Ability Group

Factor pair	FIML estimates of intercorrelations							
	Unpartialed estimates				Partialed estimates			
	Low	Mid	High	Sig. diff.	Low	Mid	High	Sig. diff.
				Wave 1				
n	440	361	442		440	361	442	
Vision, Hearing	.23	.24	.14		.11	.09	.11	
Vision, Speed	.29	.17	.08	B*	.23	.14	.03	B*
Vision, Memory	.30	.13	.07	B**	.17	.05	.14	B*
Vision, Verbal	.26	.06	.22	A**, B**	.23	.11	.22	A**
Hearing, Speed	.22	.11	.15		.12	.03	.08	
Hearing, Memory	.30	.22	.27		.15	.09	.12	
Hearing, Verbal	.15	.16	.27		.08	.17	.32	B**, C**
Speed, Memory	.49	.15	.44	A**, C**	.39	.18	.41	C*
Speed, Verbal	.43	.17	.31		.35	.16	.29	A*, B**, C*
Memory, Verbal	.63	.53	.78		.55	.61	.98	B**, C**
				Wave 3				
n	313	303	381		313	303	381	
Vision, Hearing	.28	.20	.09	B*	.03	.01	.03	
Vision, Speed	.35	.22	.28	A*, B*	.06	.08	.20	
Vision, Memory	.33	.21	.16	A*, B**	.09	.08	.13	
Vision, Verbal	.30	.02	.16	A*, B*	.22	.05	.16	
Hearing, Speed	.39	.24	.14	A*, B**	.11	.04	.07	
Hearing, Memory	.32	.23	.24		.07	.05	.12	
Hearing, Verbal	.21	.18	.22	B*	.10	.15	.23	
Speed, Memory	.67	.52	.39	A*, B**	.54	.44	.37	
Speed, Verbal	.42	.30	.35		.31	.29	.34	
Memory, Verbal	.69	.68	.53		.65	.73	.60	
				Wave 6				
n	74	126	198		74	126	198	
Vision, Hearing	.36	.27	.13		.15	.10	.08	
Vision, Speed	.25	.34	.22		.07	.20	.15	
Vision, Memory	.26	.29	.35		.07	.14	.34	
Vision, Verbal	.17	.12	.30		.05	.02	.32	
Hearing, Speed	.50	.23	.13	A*, B**	.23	.06	.08	
Hearing, Memory	.30	.23	.14		.03	.08	.05	
Hearing, Verbal	.21	.21	.16		.04	.12	.21	
Speed, Memory	.76	.48	.55	A*, B*	.63	.36	.54	
Speed, Verbal	.67	.54	.62		.61	.48	.62	
Memory, Verbal	.87	.74	.66		.84	.72	.68	

Note. FIML = full information maximum likelihood; Sig. diff. = significant difference; A = significant difference in size of correlation between low ability and mid-ability; B = significant difference in size of correlation between low ability and high ability; C = significant difference in size of correlation between mid-ability and high ability.
* $p < .05$. ** $p < .01$.

Hearing, Vision and Speed, Vision and Memory, Vision and Verbal, Hearing and Speed, Hearing and Verbal, and Speed and Memory. There were no instances of the mid-ability group having larger correlations between factors than the high-ability group, indicating that ability dedifferentiation occurs at the low end of the ability distribution. Effect sizes were small to large and ranged from 1% to 30%.

By Wave 6, dedifferentiation effects were only present for associations between Hearing and Speed and Speed and Memory, and, again, these were between the low-ability group and the other two groups. Effect sizes ranged from 20% to 35%. For the unpartialed analyses, there were 20/90 significant ability dedifferentiation effects and 2/90 effects in the unexpected direction. In the partialed analyses, 5/90 dedifferentiation effects were found. These results provide some weak support for the ability-dedifferentiation hypothesis in the unpartialed analyses. Given the large number of comparisons made, the findings from the partialed analyses may have occurred by chance, suggesting that ability

dedifferentiation, when it occurs, can be explained by demographic and health variables.

Patterns of Dedifferentiation According to Subsequent Attrition Status

Table 5 shows the intercorrelations among factors for the three attrition groups. If attrition were associated with dedifferentiation, then we would expect W1Clin to have higher intercorrelations among factors than W3Clin and W3Clin to have higher intercorrelations among factors than W6Clin. There was a general pattern of correlations decreasing in size from W1Clin to W3Clin and from W3Clin to W6Clin in the unpartialed analyses. Significant differences were found between W1Clin and W3Clin for Hearing and Speed. Significant differences were found between W1Clin and W6Clin for Vision and Hearing, Vision and Speed, Hearing and Speed, and Speed and Verbal. Effect sizes ranged from 9% to 11%. In the adjusted analyses, effects remained for Vision and Hearing and Hearing and Speed for W1Clin versus W6Clin.

In the unpartialed analyses, 6/30 significant effects were found; 3/30 were found in the partialed analyses. There were no significant effects in the unexpected direction.

Longitudinal Patterns of Dedifferentiation

Table 6 shows the intercorrelations between pairs of factors for young-old and mid-old groups derived from longitudinal analyses. All cognitive and sensory factors except Verbal were covaried. In these analyses, the background variables were regressed on the cognitive and sensory factors so the results are partialed for age, sex, education, and health (Figure 3). Longitudinal dedifferentiation would be evident if the correlations increased at each successive wave. Too much data were missing in the old-old group to enable the testing of the longitudinal model. For the young-old group, there was evidence of dedifferentiation between Wave 1 and Wave 3 for Vision and Hearing and evidence of dedifferentiation between Wave 1 and Wave 3 and between Wave 3 and Wave 6 for Speed and Memory, with an increase in 12% of shared variance. For the mid-old group, there was evidence of dedifferentiation between Wave 1 and Wave 6 for Vision and Speed and evidence of dedifferentiation between Wave 3 and Wave 6 for Vision and Speed, Vision and Memory, and Speed and Memory. Dedifferentiation did not occur between Wave 1 and Wave 3 for any factor pair. In total, there were 6/36 significant age-dedifferentiation effects in the partialed longitudinal analyses.

Table 7 shows the intercorrelations between pairs of factors for the mid-ability and high-ability groups derived from longitudinal analyses. For the mid-ability group, there was significant dedifferentiation of between 17% and 49% between Wave 1 and Wave 3 for Vision and Speed and for Vision and Memory, but there was no dedifferentiation between Wave 3 and Wave 6. For the high-ability group, there was significant dedifferentiation between Wave 1 and Wave 3 for Vision and Speed (7%) and significant dedifferentiation between Wave 3 and Wave 6 for Vision and Memory (10%) and Speed and Memory (14%). Analyses conducted on the full W6Clin subsample (n = 525) revealed dedifferentiation between Speed and Memory only. There were 9/36 significant ability dedifferentiation effects in the longitudinal analyses.

In summary, the longitudinal analyses showed weak evidence of age dedifferentiation occurring over time. When stratified by ability, patterns of dedifferentiation were more evident. Stronger effects were observed in the mid-ability group compared with the high-ability group. However, dedifferentiation effects occurred in the minority of cases.

Discussion

The dedifferentiation hypothesis has a long history in the fields of intelligence and individual differences, but it has rarely been

Table 5
Intercorrelations Among Pairs of Factors Based on Attrition Status

	FIML estimates of intercorrelations							
	Unpartialed estimates				Partialed estimates			
Factor pair	W1Clin	W3Clin	W6Clin	Sig. diff.	W1Clin	W3Clin	W6Clin	Sig. diff.
n	440	361	442		440	361	442	
Vision, Hearing	.34	.22	.09	B**	.21	.07	.02	B*
Vision, Speed	.47	.40	.26	B*	.36	.24	.22	
Vision, Memory	.30	.30	.24		.13	.16	.17	
Vision, Verbal	.39	.35	.17	B*	.33	.25	.16	
Hearing, Speed	.37	.22	.10	A*, B*	.24	.03	.03	A**, B**
Hearing, Memory	.30	.26	.26		.10	.10	.13	
Hearing, Verbal	.26	.25	.19		.10	.12	.23	
Speed, Memory	.64	.61	.56		.58	.51	.53	
Speed, Verbal	.61	.61	.46	B*	.58	.55	.48	
Memory, Verbal	.72	.72	.77		.63	.68	.86	

Note. FIML = full information maximum likelihood; W1Clin = participants who completed the clinical assessment at Wave 1 only; W3Clin = participants who completed the clinical assessment at Wave 3 but not Wave 6; W6Clin = participants who completed the clinical assessment at Wave 6; Sig. diff. = significant difference; A = significant difference in size of correlation between W1Clin and W3Clin; B = significant difference in size of correlation between W1Clin and W6Clin; C = significant difference in size of correlation between W3Clin and W6Clin.
* $p < .05$. ** $p < .01$.

Table 6
Intercorrelations Among Factors Derived From Longitudinal Analyses for Age Groups

	Partialed FIML estimates of intercorrelations							
	Young-old				Mid-old			
Factor pair	Wave 1	Wave 3	Wave 6	Sig. diff.	Wave 1	Wave 3	Wave 6	Sig. diff
Vision, Hearing	.06	.13	.07	A*	.12	.07	.08	
Vision, Speed	.20	.11	.09		.25	.11	.39	B*, C*
Vision, Memory	.01	.00	.17		.31	.12	.33	C*
Hearing, Speed	.02	.06	.13		.10	.21	.13	
Hearing, Memory	.09	.01	.10		.10	.16	.21	
Speed, Memory	.37	.52	.56	B**, C*	.68	.52	.64	A**, C**

Note. FIML = full information maximum likelihood; sig. diff. = significant difference; A = significant difference in size of correlation between Wave 1 and Wave 3; B = significant difference in size of correlation between Wave 1 and Wave 6; C = significant difference in size of correlation between Wave 3 and Wave 6. The old-old subsample was too small to allow for estimation of parameters in the longitudinal model. Effects of age, sex, Center for Epidemiologic Studies Depression Scale score, number of medical conditions, self-rated health, and education were partialed from all longitudinal results.
* $p < .05$. ** $p < .01$.

tested on a large, population-based sample of very old adults. Classic dedifferentiation hypotheses would predict that as people age, the boundaries between discrete cognitive abilities blur and the correlations among them increase. More recently, theorizing about cognitive aging, particularly the common cause hypothesis (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994), has extended this view to include the possibility that convergence not only may be in the cognitive domain but also may be cross-domain. Specifically, it has been suggested that with aging, a common factor related to changes in the underlying neurophysiology of the brain contributes to a merging of cognitive and sensory function. Therefore, our investigation addresses theoretical questions arising from the tradition of classic psychometric intelligence and the more contemporary cognitive aging perspective.

Another theme in the cognitive aging literature relevant to the present study is the importance of distinguishing between chronological age as an index of time and the physiological and contextual processes that may index adult development in a manner that is more informative for explaining cognitive change (Birren & Cunningham, 1985; Wohlwill, 1970). There have been few empirical attempts to do this, although Anstey et al. (1993), Anstey and Smith (1999), and Cunningham (as cited in Birren & Cunningham, 1985) demonstrated that biomarkers such as vision, hearing, and respiratory function indexed cognitive performance better than did chronological age. Recently, Sliwinski, Hofer, Hall, Buschke, and Lipton (in press) have also demonstrated that attrition may serve as an index of normative aging influences in a longitudinal study and that time to diagnosis of dementia in a sample of initially healthy adults may also be used to index the

Table 7
Intercorrelations Among Factors Derived From Longitudinal Analyses for Ability Groups

	Partialed FIML estimates of intercorrelations							
	Mid-ability				High ability			
Factor pair	Wave 1	Wave 3	Wave 6	Sig. diff.	Wave 1	Wave 3	Wave 6	Sig. diff
Vision, Hearing	.36	.03	.23	C*	.01	.06	.06	
Vision, Speed	.29	.66	.57	A**, B**	.08	.16	.21	A**, B*
Vision, Memory	.34	.54	.01	A**, C*	.16	.28	.35	B**, C*
Hearing, Speed	.17	.05	.14	A*	.16	.25	.09	
Hearing, Memory	.18	.09	.07		.12	.14	.03	
Speed, Memory	.24	.74	.25	B**, C*	.57	.42	.57	B*, C**

Note. FIML = full information maximum likelihood; sig. diff. = significant difference; A = significant difference in size of correlation between Wave 1 and Wave 3; B = significant difference in size of correlation between Wave 1 and Wave 6; C = significant difference in size of correlation between Wave 3 and Wave 6. The low-ability subsample was too small to allow for estimation of parameters in the longitudinal model. Effects of age, sex, Center for Epidemiologic Studies Depression Scale score, number of medical conditions, self-rated health, and education were partialed from all longitudinal results.
* $p < .05$. ** $p < .01$.

measurement of cognitive change (Sliwinski, Hofer, & Hall, in press). The issues of the validity of using chronological age as a valid metric for studying individual differences in late-life cognitive development and the extent to which sensory variables are associated with chronological age because they index age rather than cognition are central to the interpretation of the results of the present study. They underlie the rationale for stratifying the sample along dimensions of ability and attrition, in addition to age.

Our first aim was to test the traditional cognitive dedifferentiation hypothesis with respect to age. We found weak and inconsistent evidence in support of dedifferentiation associated with age in the unpartialed analyses and virtually no evidence of dedifferentiation associated with age in the partialed analyses. Even though the sample was selected using the electoral roll, it is likely that older participants at Wave 1, particularly those over 85 years old, constituted a highly selected group who had survived longer than the population average and were well enough to participate in a research study. This inescapable selection bias, present in all studies similar to the present one, would have the effect of reducing observed dedifferentiation associated with age. Fortunately, our longitudinal analyses enabled us to isolate the aging effects from the selection effects by permitting analysis of dedifferentiation with the same subsamples over time. Longitudinal analyses supported the cross-sectional analyses. They did not reveal consistent patterns of dedifferentiation for any pair of factors. The overall picture presented by the longitudinal analyses is that dedifferentiation is not a pattern that could be used to describe overall age changes. The longitudinal results suggest that the lack of age effects observed cross-sectionally could not be explained in terms of sampling bias. Given the different time intervals between our occasions of measurement (2 years between Waves 1 and 3, and 6 years between Waves 3 and 6), we would expect greater dedifferentiation to occur between the last two occasions of measurement than between the first two. This did not occur. The confirmation of cross-sectional findings by longitudinal findings on the same sample provides a robust result.

Our second aim was to test whether dedifferentiation was also observed in the present study in relation to cognitive ability. There was some evidence of dedifferentiation in the low-ability group compared with the other ability groups at Wave 3. This effect was eliminated once demographic and health variables were partialed out of the analyses. Wave 3 and Wave 6 had isolated instances of dedifferentiation (e.g., between Hearing and Speed and between Speed and Memory) that were eliminated after partialing out the effects of demographic and health variables. Longitudinal analyses provided some evidence for ability dedifferentiation for correlations involving Vision, even though the low-ability group was too small to be included. There was no evidence of ability dedifferentiation for any pairs of associations involving Hearing. Our results are somewhat consistent with findings in young samples by Deary et al. (1996), who reported dedifferentiation was present only in the lower ability groups. We conclude that there is inconsistent evidence (i.e., occurring for some but not all associations among factors) of a dedifferentiation effect in the low-ability group in the present study. In the few instances where ability dedifferentiation occurred, the overall patterns of change in size of correlations were inconsistent. There were few instances of a systematic increase of association from high to low ability and few instances where the same correlations showed dedifferentiation effects in both cross-sectional and longitudinal analyses. Therefore, even though instances of dedifferentiation could be identified, overall patterns of dedifferentiation for particular factor pairs were not found.

Our third aim was to investigate the effect of attrition on dedifferentiation to gain an insight into how selection factors, present in both cross-sectional and longitudinal aging studies, influence the observed factor structure among cognitive and sensory abilities. Our results showed an inconsistent pattern of weak to moderate dedifferentiation associated with early attrition from the study, with participants who only completed the first clinical assessment having the largest associations among sensory and cognitive factors. Adjusting for demographic and health variables reduced the size of the associations among cognitive and sensory factors and the significant effects from 20% to 10%.

A possible interpretation of the finding of some dedifferentiation associated with attrition is that it reflects terminal drop (Berg, 1996) and is only evident during a state of decline preceding death. This is plausible because the participants in the samples studied were very old, and the majority of attrition was due to mortality, so that measurements taken prior to mortality may reflect terminal drop.

Our fourth aim was to determine whether dedifferentiation occurred longitudinally within the same subsamples defined according to either ability or age. The longitudinal results revealed more evidence in support of ability dedifferentiation than age dedifferentiation but confirmed that dedifferentiation effects occur in a minority of cases and that systematic patterns of dedifferentiation were absent from the present study. Despite the longer interval between Wave 3 and Wave 6 than between Wave 1 and Wave 3, the longitudinal results did not reveal larger dedifferentiation effects between Wave 3 and Wave 6 than between Wave 1 and Wave 3. All of the background variables included in this study have been associated with attrition and mortality in previous analyses (Anstey, Luszcz, Giles, & Andrews, 2001; Anstey & Luszcz, 2002), so controlling for these variables partials out many of the health and demographic factors for which age, ability, and attrition are proxies. Thus, the partialed analyses provide conservative estimates of dedifferentiation (Storandt & Hudson, 1975).

Our results have important implications for common factor theories of cognitive aging. Dedifferentiation between abilities of different domains (cognitive and sensory) as well as within each domain would suggest that there is a common factor or common factors underlying some of the shared variance in cognitive and sensory aging. However, in the present study, effect sizes for increasing shared variance among factors were mostly small to moderate in size, with few instances of large effects. Effects occurred in a minority of cases, and overall patterns of dedifferentiation were lacking. This was the case even when the sample was stratified according to ability and attrition, which may be more accurate indices of cognitive development in this very old sample.

The lack of consistent patterns of dedifferentiation within the sample longitudinally is as important as the size of the effects found. Common factor theories imply that dedifferentiation effects occur consistently with and between cognitive and sensory domains. However, the absence of patterns of dedifferentiation in the present study suggests that independent processes underlie differ-

ent aspects of cognitive development. Therefore, the results of the present study suggest that a number of independent factors combine to produce parallel aging in sensory and cognitive abilities that give the impression of a common factor when viewed cross-sectionally. Although our results do not rule out the possibility of common processes underlying the specific elements of sensory and cognitive aging, there is a greater need for identification of the many specific factors that must result in decline in these abilities. Independent disease processes or specific areas of neuronal atrophy may underlie specific aspects of cognitive and sensory decline. Clearly, more research is required to identify these specific factors that are associated with intellectual development in the very old. An increased emphasis of the specific nature of aging processes is also emerging in the broader field of neuroscience. Research on neuronal changes in normal aging and Alzheimer's disease now shows that age-related reduction is specific to cortical layer and region (Uylings & de Brabander, 2002). This is in contrast with the previous view that more generalized cell loss occurrs in normal aging (Petit, 1982). Specific associations between cognitive and sensory decline may reflect neuronal cell loss, dendritic degeneration, and synapse reduction in pathways affecting specific combinations of cognitive and sensory functions measured behaviorally. Experimental studies and functional MRI studies may be the best methods by which to identify cognitive and sensory abilities that draw on common neuronal resources (K. Z. H. Li & Lindenberger, 2002).

Previous studies reporting substantial shared variance in cognitive and sensory test performance in old age have been cross-sectional (e.g., Anstey, Luszcz, & Sanchez, 2001a; Lindenberger & Baltes, 1994). It is only with the availability of longitudinal data such as those presented here that proper testing of theories about aging derived from cross-sectional studies is possible. However, recent work has shown that theoretical explanations based on studies of age differences are not necessarily validated when data on age changes become available. For example, Sliwinski and Buschke (1999) showed that processing speed accounted for 70% to 100% of age differences in cognitive test performance but only 6% to 29% of age changes in cognitive test performance. Results from the present study are consistent with other cross-sectional studies in demonstrating that cognitive and sensory function are correlated in very old adults. However, they also show that the strength of associations among cognitive and sensory factors within individuals does not increase to the degree that would be expected on the basis of studies of between-individual differences.

Statistical modeling techniques used in cross-sectional studies may be partly responsible for the development of common factor theories. Models supporting a common factor have been specified at a global level using factor analytic techniques that allow cognitive tests or cognitive abilities to load onto a single factor (e.g., Anstey & Smith, 1999; Christensen et al., 2001; Lindenberger & Baltes, 1994). Although single-factor models can reveal specific associations between variables (e.g., Anstey, Luszcz, Giles, & Andrews, 2001; Christensen et al., 2001; Lindenberger & Baltes, 1994), they still emphasize shared variance among factors. Analyses revealing more specific associations and a lack of associations between specific cognitive and sensory factors have not used single-factor analytic models to describe the relationships among cognitive and sensory variables and hence allow for greater specificity of associations to be identified (e.g., Anstey et al., 2001b; Anstey et al., 2002). Part of the motivation for researchers to use common factor models has been to provide parsimonious accounts of the many processes in aging. However, as research progresses in this field, it is becoming evident that common factor theories may oversimplify the true nature of cognitive and sensory change. As shown in the present study, more complicated and specific theories are required to account for the mixture of associations among rates of change that occur and the many factors that influence them. The approach of the present study, to test for increases in size between specific factors, is based on the view that theoretical advances in this field require knowledge of specific associations among cognitive and sensory abilities that may be overlooked where common factor models are specified in the first instance.

At this point, it is valuable to consider how the results of the present study relate to findings referred to as dedifferentiation from the field of neuroimaging. Neuroimaging studies show that older adults have increased bilateral activation on tasks that require activation in only one hemisphere in younger adults (Cabeza, 2001, 2002). Cabeza suggested that this could be viewed as evidence for the dedifferentiation hypothesis, although he favored a compensation hypothesis on the basis of current evidence. Park et al. (2002) argued that these findings may be evidence for the deterioration of domain-specific distinctions between memory structures over the life span. Theories of dedifferentiation arising from neuroimaging studies describe and provide explanations for observed patterns of brain activation during the execution of information-processing tasks. However, as noted by Park, Polk, Mikels, Taylor, and Marshuetz (2001), the term *dedifferentiation* has different meanings when used in different fields. There is as yet no substantive reason to link dedifferentiation occurring at the level of neural recruitment and dedifferentiation observed in relation to psychometric data. It may be the case that the use of a common term confuses rather than clarifies the role of brain activation in relation to statistical associations among psychometric test scores. We note that Park et al. (2002) reported finding no evidence of dedifferentiation in performance on memory tasks at the behavioral level.

The results of the present study must be considered in the context of their strengths and limitations. They represent a thorough empirical evaluation of the theory of dedifferentiation using structural equation modeling techniques. Statistical significance tests lacking from many previous studies are used, as are optimal techniques for dealing with missing data. Most work on dedifferentiation has been conducted on cross-sectional studies, whereas the present study reports results for the same individuals over three occasions of measurement, allowing for validation of results within a single study and sample. Another strength of the present study is that potentially confounding variables were partialed out of the analyses, providing a purer estimation of trends in the size of factor intercorrelations between groups. However, the total number of analyses we reported incorporated a large number of statistical tests that would lead to Type I errors. We also analyzed the same data set several times using different methods of stratifying the data. Therefore, the tests of significance should be used as a guide to interpret the range of results presented and to identify general trends within each set of analyses rather than being seen as placing emphasis on individual tests. Without presenting some

evaluation of whether correlations differ in size, we may be in danger of overinterpreting small differences in size. Even though there was a probability of us reporting results that were significant by chance, we still found few significant dedifferentiation effects. Isolated effects were mostly weak to moderate in size and were inconsistent in that the same effects were not significant in all analyses. If, for example, we had found that dedifferentiation effects were significant for Vision and Memory in all analyses, even though no other effects were significant, then we could be confident in arguing that dedifferentiation occurs between vision and memory in old age. Unfortunately, we did not find consistent patterns between cross-sectional and longitudinal analyses or even from wave to wave in cross-sectional analyses.

Despite the limitations of this study, the overall picture of dedifferentiation gained is extremely comprehensive, enabling some firm conclusions to be drawn. Neither age nor aging was strongly associated with dedifferentiation, but low ability and early attrition from the study were associated with some instances of dedifferentiation. Dedifferentiation effects, when they occurred, were never present across the full range of cognitive and sensory associations, but in most cases there was a mix of cognitive and sensory factors involved. That is, dedifferentiation, when it occurs, is not specific to cognitive abilities and may involve a combination of one sensory and one cognitive ability. Despite our systematic search for dedifferentiation at the level of within-wave correlations, patterns of dedifferentiation were not found.

The results of the present study are based on a large, population-based sample of very old adults and objective measures of cognitive and sensory function at three time points. Although the present study is limited by the range of cognitive measures included and by the range of cognitive factors sampled, it is unique in having sensory data on such a large representative sample over 8 years. Interpretation of our results was strengthened by the use of statistical significance tests rarely used in this field, converging evidence from cross-sectional and longitudinal approaches, and the control of potentially confounding variables. Therefore, we conclude that the lack of dedifferentiation associated with age and aging, the weak evidence of dedifferentiation in the low-ability group (albeit only an inconsistent effect), and the instances of dedifferentiation between cognitive and sensory domains are robust findings. Overall, our results do not support a theory of dedifferentiation of cognitive and sensory abilities in very old adults. These findings should form a strong platform for the further development and discussion of theories relating cognitive and sensory function in later life.

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