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Cognitive Dedifferentiation With Increasing Age and Proximity of Death: Within-Person Evidence From the Seattle Longitudinal Study

Gizem Hülür
Humboldt University of Berlin

Nilam Ram
The Pennsylvania State University and German Institute for Economic Research, Berlin, Germany

Sherry L. Willis and K. Warner Schaie
University of Washington

Denis Gerstorf
Humboldt University of Berlin and The Pennsylvania State University

A central aim of life-span psychology is to understand ontogenetic changes in the structure of individuals' actions, thoughts, and behaviors. The dedifferentiation hypothesis of cognitive aging suggests that the structure of individuals' cognitive abilities becomes less differentiated in old age. Empirical tests have almost exclusively approached this hypothesis from a between-person difference perspective and produced a mixed set of findings. In the present study, we pursue a within-person test of the hypothesis using up to 8 repeated measures of cognitive abilities over up to 49 years, covering fluid (inductive reasoning), visualization (spatial orientation), and crystallized abilities (number, verbal meaning, and word fluency), obtained from 419 now-deceased individuals who participated in the Seattle Longitudinal Study (SLS) and have provided at least 4 observations for each cognitive test. Results revealed that with advancing age and proximity to death, within-person coupling increased (a) among the crystallized abilities, (b) between visualization and fluid abilities, (c) between visualization and crystallized abilities, and (d) between fluid abilities and crystallized abilities. We discuss the importance of within-person analyses for understanding changes in the structure of behavior and consider how our findings inform research on cognitive decline and dedifferentiation later in life.

Keywords: dedifferentiation, longitudinal, cognitive aging, terminal decline

Developmental researchers are interested in ontogenetic changes in the structure and organization of behavior (Baltes, Cornelius, Spiro, Nesselroade, & Willis, 1980; Reinert, 1970; Riegel & Rosenwald, 1975). For example, since the 1940s, a number of studies have examined cognitive dedifferentiation, that is, whether the organization of cognitive ability among adults moves toward a more consolidated structure with increased age (e.g., Balinsky, 1941; Baltes & Lindenberger, 1997; Ghisletta & Lindenberger, 2003). However, evidence for age-related dedifferentiation is mixed, and has relied almost exclusively on analysis of age-group differences in the structure of sample-level (between-person) associations among cognitive abilities. In the present study, we approach cognitive dedifferentiation from a within-person perspective to examine age- and mortality-related cognitive dedifferentiation across the adult life span (early adulthood to very old age and death) as a within-person process using data from the Seattle Longitudinal Study (SLS), a study wherein fluid (inductive reasoning), visualization (spatial orientation), and crystallized abilities (number, verbal meaning, and word fluency) were assessed on up to eight waves over up to 49 years.

Gizem Hülür, Department of Psychology, Humboldt University; Nilam Ram, Department of Human Development and Family Studies, The Pennsylvania State University and German Institute for Economic Research, Berlin, Germany; Sherry L. Willis and K. Warner Schaie, Department of Psychiatry and Behavioral Sciences, University of Washington; Denis Gerstorf, Department of Psychology, Humboldt University and Department of Human Development and Family Studies, The Pennsylvania State University.

Correspondence concerning this article should be addressed to Gizem Hülür, Department of Psychology, Humboldt University Berlin, Unter den Linden 6, 10099, Berlin, Germany. E-mail: gizem.hueluer@hu-berlin.de

The Dedifferentiation Hypothesis

The notion that both level of cognitive abilities and their organizational structure changes with age was formulated early in the history of psychometric studies on intelligence. Spearman (1927) was among the first to observe that associations between cognitive abilities changed with ability level; and he proposed that the organization of cognitive abilities may also change with age. The "age differentiation hypothesis" was introduced by Garrett (1946), who argued that with increasing age in childhood, the organization of intelligence moves from a single general ability toward a group of less closely associated abilities (see Hülür, Wilhelm, & Robitzsch, 2011). Balinsky (1941) examined the age differentiation hypothesis across the life span and observed that the structure of cognitive abilities shifts back toward a general factor in later adulthood. Based on the age differentiation hypothesis and the work by Balinsky (1941), it was hypothesized that the structure of cognitive abilities differentiates through late childhood and early adolescence, remains in a relatively differentiated organization throughout adulthood, and then dedifferentiates in old age (Baltes et al., 1980). The first set of studies examining this possibility provided (partial) support for the dedifferentiation hypothesis (e.g., Baltes et al., 1980; Cunningham, 1980; Hayslip & Sterns, 1979).

In recent years, a number of studies have examined cognitive dedifferentiation during adulthood and old age as an integral component of senescence and mortality. Several conceptual accounts outline why age-related declines in cognitive abilities should be accompanied by dedifferentiation: First, it has been proposed that age-related decline processes compress the structure of cognitive abilities by imposing constraints on their constituent processes (Li et al., 2004). For example, age-related deficits in processes associated with the encoding of stimuli could interfere with performance on measures of both fluid and crystallized abilities, manifesting as stronger links between domains. Second, the decline of sensory, motor, and CNS functions in old age has been proposed to lead to a dedifferentiated structure of cognitive abilities. Due to such declines, cognitive abilities rely increasingly on the functioning of the physiological infrastructure (Schaie, 1962; Schaie, Maitland, & Willis, 2000). Third, the relative contributions of biology and culture to cognitive abilities are assumed to change with age. Whereas environmental and experiential phenomena associated with culture dominate psychological processes in young and middle adulthood, biological resources might exert a larger influence in old age and late life (Baltes, Reuter-Lorenz, & Rösler, 2006). For example, although crystallized abilities are relatively stable or increase through adulthood (see Schaie, 2013), decrements are observed in very old age and in proximity of death (Gerstorf, Ram, Hoppmann, Willis, & Schaie, 2011; Schaie, 2013). The acquisition of crystallized knowledge can be facilitated by educational and occupational experiences throughout adulthood, but declining biological resources in very old age and in late life might make it difficult to compensate for declines in basic cognition with broad cultural or life knowledge (for a discussion, see Ghisletta & de Ribaupierre, 2005; Ghisletta & Lindenberger, 2003). This would lead crystallized abilities to be more closely coupled with fluid abilities and to a dedifferentiated ability structure in old age.

Between-Person Difference Approach Versus Within-Person Change Approach

Previous research has almost exclusively examined dedifferentiation from a between-person perspective. Cross-sectional data, by definition, only allow examination of between-person associations among the cognitive abilities, whereas longitudinal data offer the possibility to examine both between-person and within-person associations. In brief, between-person associations indicate the extent to which individuals who score higher than their peers on one cognitive ability also score higher than their peers on another ability and are quantified using sample-level covariances. Interpreting the dedifferentiation hypothesis from a between-person perspective, the prediction is that the sample-level intertest covariances are higher in samples of older adults and lower in samples of younger adults. For example, in cross-sectional data, Sims, Allaire, Gamaldo, Edwards, and Whitfield (2009) found that factor covariances were not higher in groups of older adults relative to those in groups of middle-aged adults. Thus, their findings did not support the dedifferentiation hypothesis (Sims et al., 2009), which would predict that covariances would be higher in older age groups. Similarly, in longitudinal data, Anstey, Hofer, and Luszcz (2003) showed that factor covariances were not systematically higher in later measurement waves when the sample was older. Thus, this study also did not find evidence for age-related cognitive dedifferentiation (Anstey et al., 2003).

Alternatively, repeated measures data (of sufficient number of occasions) could be used to obtain and examine within-person covariances directly (see Hülür, Hertzog, Pearman, Ram, & Gerstorf, 2014). Here, the focus is on whether a given person performs higher than usual (i.e., relative to this person's own average functioning) on one cognitive ability test on the same occasions that he or she performs higher than usual on another cognitive ability test. Interpreting the dedifferentiation hypothesis from a within-person change perspective, the prediction is that the person-specific covariances increase with age. That is, the strength of within-person couplings will be higher when a given adult is older relative to when he or she was younger. In the present study, we moved from the typical between-person proxy tests toward articulation of a within-person hypothesis. Using a multilevel modeling framework (Bryk & Raudenbush, 1992; Snijders & Bosker, 1999), we examine how within-person couplings between pairs of cognitive abilities change across age and time to death.

Cognitive Dedifferentiation Across Age

Empirical evidence for cognitive dedifferentiation from between-person examinations is mixed. Some studies report evidence for dedifferentiation in old age (Baltes & Lindenberger, 1997; de Frias, Lövdén, Lindenberger, & Nilsson, 2007; Ghisletta & de Ribaupierre, 2005; Ghisletta & Lindenberger, 2003; Li et al., 2004), whereas others do not (Anstey et al., 2003; Juan-Espinosa et al., 2002; Park et al., 2002; Sims et al., 2009; Tucker-Drob, 2009; Tucker-Drob & Salthouse, 2008; Zelinski & Lewis, 2003). Optimistically, divergent findings may result from methodological differences related to the nature of the samples (life span vs. old adult samples) and the study designs (cross-sectional vs. longitudinal). Some studies examined samples of old adults (65+ years of age) exclusively (Anstey et al., 2003; Ghisletta & de Ribaupierre, 2005; Ghisletta & Lindenberger, 2003); whereas others examined adult life span samples that also included young or middle-aged adults (Baltes & Lindenberger, 1997; de Frias et al., 2007; Juan-Espinosa et al., 2002; Li et al., 2004; Park et al., 2002; Sims et al., 2009; Tucker-Drob, 2009; Tucker-Drob & Salthouse, 2008; Zelinski & Lewis, 2003). The studies also differ with respect to whether age-related dedifferentiation was examined using a cross-sectional (Baltes & Lindenberger, 1997; Juan-Espinosa et al., 2002; Li et al., 2004; Park et al., 2002; Sims et al., 2009; Tucker-Drob, 2009; Tucker-Drob & Salthouse, 2008) or a longitudinal design (Anstey et al., 2003; de Frias et al., 2007; Ghisletta & de Ribaupierre, 2005; Ghisletta & Lindenberger, 2003; Zelinski & Lewis, 2003). Taken together, the findings indicate that longitudinal studies were more likely to find evidence for dedifferentiation, but were more likely to rely on data on old age. This suggests that the scarcity of longitudinal studies of dedifferentiation that involve the total adult life span may be contributing to the mixed findings.

Cognitive Dedifferentiation and Terminal Decline in Cognitive Abilities

Studies of cognitive dedifferentiation mainly examined changes in the structural organization of cognitive abilities across age. Previous research has shown that late-life changes in cognition can be described both as a function of age and as a function of closeness to death (Bäckman & MacDonald, 2006; Gerstorf et al., 2011; Hülür, Infurna, Ram, & Gerstorf, 2013; Ram, Gerstorf, Fauth, Zarit & Malmberg, 2010). An important, but largely unanswered question is whether the typically observed steep declines in cognitive performance close to death (i.e., terminal decline) are accompanied by a dedifferentiation of the ability structure. It is possible that mortality-related processes not only affect levels of cognitive abilities, but also their structural organization. That is, mortality-related processes of disease progression may also be a source of cognitive dedifferentiation. A longitudinal study by Sliwinski, Hofer, and Hall (2003) provides initial support for this view. This study examined cognitive change in the domains of speed, memory, and fluency in two groups of participants with and without preclinical dementia. The findings showed that within-person changes in the three cognitive domains were more closely correlated (between-persons) in the group with preclinical dementia (r = .45 to .51) as compared to the nondemented group (r = .07 to .18). These findings suggest that cognitive dedifferentiation might be associated with disease progression rather than normative age-related processes. In a similar vein, recent cross-sectional findings from Batterham, Christensen, and MacKinnon (2011) show that cognitive dedifferentiation is stronger across a time-to-death metric as compared to the metric of chronological age. Initial looks at longitudinal data also support the notion of terminal dedifferentiation of cognitive abilities. For example, Wilson, Segawa, Hizel, Boyle, and Bennett (2012) examined cognitive change across time to death in a multiphase framework and show that (between-person) correlations among rates of change in different cognitive domains were moderate (range = .25 to .46) in the preterminal phase of cognitive decline (on average, earlier than 2.6 years before death), and considerably stronger during the terminal period (range = .83 to .89; on average, 2.6 years prior to death or later). We note that the above referenced studies approach the issue from a between-person differences perspective and examine (a) whether the individuals who are closer to death show stronger associations among cognitive abilities (Batterham et al., 2011), or (b) whether the individuals who show steeper declines in one cognitive domain as compared to their peers are also more likely to show steeper declines in another cognitive domain as compared to their peers, and whether this is especially the case in the terminal period in close proximity of death (Wilson, Segawa, Hizel et al., 2012). From a within-person perspective, one can examine whether on occasions when a person scores lower than expected in one cognitive domain, he or she also scores lower than expected in another cognitive domain, and whether this link becomes stronger with proximity of death (Ram & Gerstorf, 2009). The examination of mortality-related dedifferentiation can provide further insights into the processes leading to cognitive dedifferentiation late in life. To capture age- and mortality-related influences on the structure of cognitive abilities over time, we moved the consideration from a between-person difference perspective to within-person change and examined cognitive dedifferentiation across both age- and time-to-death metrics longitudinally.

The Present Study

We examined age- and mortality-related cognitive dedifferentiation from a primarily within-person perspective. According to the dedifferentiation hypothesis, we expected greater dedifferentiation with advancing age and proximity to death, as mortality-related processes associated with disease progression may be another source of cognitive dedifferentiation. We hypothesized that associations between abilities increase with age and with time to death. We made use of performance data on five tests of Thurstone's Primary Mental Abilities (Thurstone & Thurstone, 1949) obtained on up to eight measurement occasions over up to 49 years in the SLS (for overview, see Schaie, 2013).

Method

Data for the present analyses were drawn from the SLS, an interdisciplinary longitudinal panel study that offers a particularly suitable context for examination of cognitive dedifferentiation because the study has followed a substantial number of individuals for almost a half-century, repeatedly collecting data on a broad set of cognitive abilities as individuals moved across the entire adult life span, early adulthood to very old age. Detailed descriptions of the study design can be found in Schaie (2013). Select details relevant to the present study are presented below.

Participants and Procedure

The SLS has, since 1956, collected repeated measures on close to 6,000 participants aged between 22 and 101 years in a cohort-sequential design. Participants were members of a HMO in the Seattle metropolitan area, and recruited randomly according to gender and age/cohort groups (22 to 70 years old). The sampling frame consisted of community-dwelling individuals from various occupational, educational, and economic backgrounds (Schaie, 2013). Data collection took place at 7-year intervals since 1956. At each wave, new participants were added to the sample over the age range of 22 to 84 years plus a 7-year interval to match the current age range of the initial sample (with the exception of the 1963 wave, where the age range of new participants was 22 to 70 years old). All participants completed a battery of cognitive measures at each wave. The subsample analyzed here includes now-deceased participants of the SLS who provided at least four observations for each cognitive test (N = 419). This subsample included individuals who started participating in the SLS in 1956, 1963, 1970, 1977, or 1984. Demographic characteristics for this subsample are given in Table 1. During the course of the study, 61 participants (14.56% of this subsample) have been identified as having dementia based on a) information from the neuropsychological assessment and neuropsychologists rating the subjects as demented based on their test performance, b) their medical records, or c) reports by their family. The dementia prevalence in our subsample (average age at death: 84.52 years, see Table 1) was comparable to recent meta-analytic estimates for U.S. Americans aged 80 to 84 years (11.9%; Prince et al., 2013). In total, we used longitudinal data obtained on eight measurement occasions at 7-year intervals

Table 1
Descriptive Statistics for Sociodemographic Variables

	Participants with at least 4 observations (n = 419)			Participants with less than 4 observations (n = 1,357)			
	M	*SD*	Range	*M*	*SD*	Range	Cohen's *d*
Age at T1	48.50	10.20	23–72	64.46	11.57	22–86	−1.46*
Gender (0 = men, 1 = women)	0.52	0.50	0–1	0.46	0.50	0–1	0.12*
Years of formal education	14.13	2.84	8–20	12.49	3.41	1–20	0.52*
Age at death	84.52	9.06	57–104	81.37	10.81	34–106	0.32*

* $p < .05$.

over up to 49 years (1956, 1963, 1970, 1977, 1984, 1991, 1998, and 2005).

To examine how our inclusion criterion that individuals had provided at least four observations impacted sample selectivity, we compared participants in the present sample (n = 419) with a subsample of now-deceased participants who started participating in the SLS at the same waves (1956, 1963, 1970, 1977, 1984), but provided less than four observations (n = 1,357, see Table 1). Compared to this larger subsample, the subsample in the present study included individuals who were younger at T1, more women, more educated individuals, and individuals who died at older ages.

Measures

The present analysis makes use of five subtests from the 1948 PMA 11–17 version of Thurstone's Primary Mental Abilities Test (Thurstone & Thurstone, 1949) that have been assessed at every wave since study inception. *Number ability*, *verbal meaning*, and *word fluency* are interpreted as indicators of crystallized ability, *inductive reasoning* as an indicator of fluid ability, and *spatial orientation* as an indicator of visualization ability (Bosworth, Schaie, & Willis, 1999; Bosworth, Schaie, Willis, & Siegler, 1999).

Crystallized abilities were assessed with tests of number ability, verbal meaning, and word fluency. Number Ability was measured using a test of simple addition skills where participants must decide whether a given arithmetic problem was solved correctly. Number ability is scored as the difference between the frequencies of correct versus wrong responses. Verbal meaning measures an individuals' ability to recognize verbal meaning. Participants were presented with words and asked, for each item, to indicate the correct synonym out of four alternatives. The word fluency test assesses an individual's ability retrieve words from long-term memory according to a lexical rule, including common nouns, but not proper nouns. Participants were asked to name as many words beginning with the letter *S* as possible within a specified time limit. Scores were based on the number of valid words produced within 5 minutes. Fluid ability was measured by a test of *inductive reasoning*. Inductive reasoning is a test that measures an individual's ability to induct the rules according to which letter series are formed. Participants were given alphabetic series and asked to select from among six letters the letter that logically followed in the sequence. Successful completion requires both planning and logical problem solving. Visualization ability is indicated by a test of *spatial orientation*. Spatial orientation was measured using a test requiring visualization of object rotations in two-dimensional space. Participants were given a stimulus figure and were asked to indicate each of the six response figures that are a rotation and not a mirror image of the stimulus.

Raw scores on each cognitive test were scaled to a T score metric (M = 50, SD = 10), with first occasion scores of the entire SLS sample as reference (see Schaie, 2013). Test–retest reliabilities over 1 month were high for all tests (based on a subsample of N = 705; $r \geq .78$; see Schaie, 2013).

Age and time to death. Chronological age at each measurement occasion was calculated as the number of years since an individual's birth. The age variable was coded in integer numbers and centered at 82.52 years, 2 years prior to the average age at death of 84.52 years, in order that parameter estimates from the age-based models were located in a similar place as the time-to-death-based models, where time to death was centered at 2 years prior to death (outlined below). Time to death at each measurement occasion was calculated as the difference between the year of assessment and the year of an individual's death obtained either from family members, Social Security death records, or the HMO. Time to death was coded as integer numbers and centered at 2 years prior to death, a location in time where terminal decline effects were very likely to have set in (e.g., Sliwinski et al., 2006; Wilson, Beck, Bienias, & Bennett, 2007; Wilson, Beckett, Bienias, Evans, & Bennett, 2003; Wilson, Segawa, Hizel et al., 2012). Figure 1 shows the frequencies of observations over chronological age and time to death. Age and time to death were scaled in decades to facilitate interpretation of model parameters.

Data Analysis

Cognitive dedifferentiation was operationalized as the age- or time-to-death-related change in the extent of within-person coupling between pairs of cognitive abilities. For clarity, we describe the analytical methods using two example abilities, number ability and spatial orientation. However, all procedures were applied to all pairs of abilities. First, we preprocessed the data to remove any long-term person-specific developmental trends over time in study in "mean levels" of cognitive abilities. Second, we modeled age-/time-to-death-related changes in "covariances" of cognitive abilities.

Preprocessing/detrending. To keep the focus on within-person couplings, we followed standard time series preprocessing procedures to detrend each individual's data (Box & Jenkins, 1976; Chatfield, 2004; Shumway & Stoffer, 2006). Specifically, we used additive polynomials to model and remove any long-term trends in each individuals' "mean levels" for each ability. Time-

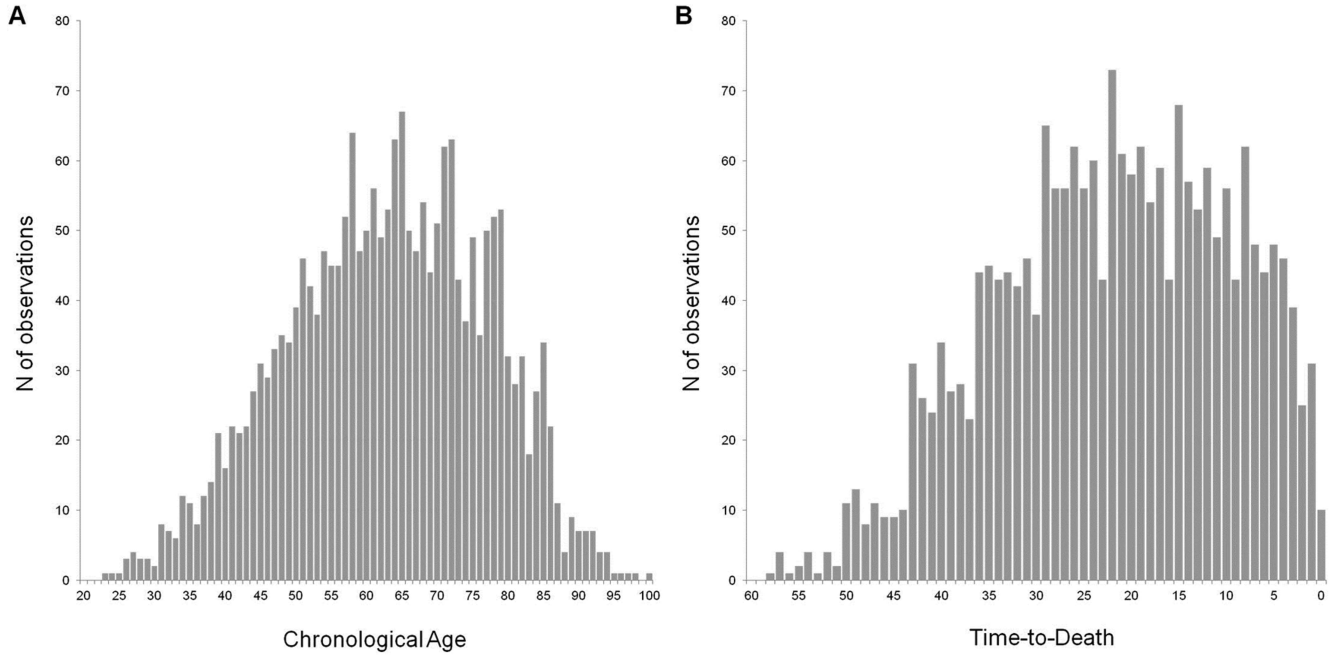

Figure 1. Frequency of observations in the Seattle Longitudinal Study (SLS) for the age model (A) and the time-to-death model (B). The models included 2,131 data points from 419 participants.

based regression models were specified and estimated (using SAS proc glm; Freund, Littell, & Spector, 1986) separately for each individual. For example, we fit the models

$$spatial_t = \beta_0 + \beta_1(time_t) + \beta_2(time_t^2) + es_t, \quad (1)$$

$$number_t = \beta_0 + \beta_1(time_t) + \beta_2(time_t^2) + en_t, \quad (2)$$

where $spatial_t$ and $number_t$, the scores for particular cognitive abilities at occasion t, are a function of intercept parameters β_o, linear slope parameters β_1 that characterizes the rate of linear change per year in study (centered at the beginning of the study), quadratic slope parameters β_2, and residual terms, es_t for spatial orientation and en_t for number ability, respectively. The residual scores (e.g., en_t and es_t) were then saved and became the focus for the analysis of dedifferentiation. Preparing the data in this way, we systematically removed between-person differences in long-term change that manifested across years. Conceptually, time in study proxies a set of individual-level, long-term developmental processes that operate on "mean levels" of cognitive ability. These processes are not the focus of the current analysis and thus were removed. The residual scores, which by definition fluctuate around zero, capture only the within-person deviations from each individual's long-term trajectory of cognitive change. Our choice to detrend at the individual level, rather than through a multilevel model of change (i.e., growth model), reflects a rather conservative approach to removal of between-person differences in long-term change (because it is not prone to the compression effects that are the hallmark of the multilevel framework). We used the GLM approach because it makes no assumptions regarding the organization of interindividual differences in intraindividual change. While a growth model does provide for unbiased prediction for the average person, the further a specific individual is away from the prototype (sample-level average), the worse the individual-level prediction. For those "outlier" individuals, the trajectory will be "compressed" toward the average trajectory, and thus, the residuals will, by necessity, be biased further outward. In contrast, when the trend is determined at the individual level using GLM, the trends for individuals who reside further away from the average curve are not "biased" toward the mean and thus may account for a greater proportion of variance. This can be viewed as a more conservative stance that prioritizes attributing as much variance as possible to the trends—so that less is available for the second step analysis of the residuals that will be described in the next subsection.

It may be noted that the multilevel (growth curve) modeling and person-specific modeling approaches can both be viewed as "more conservative" —depending on the purpose of an analysis. The multilevel (growth curve) modeling approach provides for more conservative representation of the trends, at the cost of biased individual-level representation. The person-specific modeling approach provides for more conservative interpretation of the residuals, at the cost of allowing individual trends to bias the group-level representation. In the present study, our interest was in the individual-level residuals, so we were not concerned if individual trends looked substantially different from the average, group-level trend. We aimed at discarding as much variance as a linear + quadratic functional form (growth curve) would allow in order that the residual time-series is a conservative measure of individual-level fluctuations.

Dedifferentiation. We used a multilevel modeling framework (Snijders & Bosker, 1999; implemented using SAS Proc Mixed; Littell, Milliken, Stroup, & Wolfinger, 1996) to examine the couplings between the detrended cognitive scores (e.g., es_t and en_t) and how those couplings changed across age and time to death.

Age or time to death was used as proxy for long-term developmental processes that operate on "covariance" of cognitive abilities. Specifically, extent of cognitive dedifferentiation was operationalized as the rate of age-related (or mortality-related) change in the within-person couplings. For example, the ability scores were modeled (at Level 1) as

$$en_{ti} = \alpha_{1i}(es_{ti}) + \alpha_{2i}(es_{ti} * age_{ti}) + \alpha_{3i}(es_{ti} * age^2_{ti}) + r_{ti}, \quad (3)$$

where es_{ti} and en_{ti} are person i's scores for spatial orientation and number ability at occasion t, α_{1i} is a person-specific coupling parameter that characterizes the strength of the coupling between the two cognitive abilities at age 82.52 (centering age), and α_{2i} and α_{3i} are parameters that characterize the rate at which the coupling changes with *age* and *age*^{2}. The differentiation theory has only specified the direction, but not the functional form—so we explored the possibility of both linear and quadratic change. Our experience working with large swaths of adulthood (as exist here in SLS), suggests the presence and need to accommodate nonlinear trajectories. Quadratic forms provide a lower bound.

Note that the model does not include an intercept term because all between-person differences in ability levels were removed during preprocessing/detrending. Between-person differences in coupling were modeled (at Level 2) as

$$\alpha_{1i} = \gamma_{10} + u_{1i}, \quad (4)$$

$$\alpha_{2i} = \gamma_{20}, \quad (5)$$

$$\alpha_{3i} = \gamma_{30}, \quad (6)$$

where γ_{10}, γ_{20}, γ_{30} indicate the average within-person coupling, rate of linear age-related change and rate of quadratic age-related change, respectively, and u_{1i} are person-specific deviations from the average coupling. To illustrate, Figure 2 shows the bivariate series for number ability and spatial orientation (after detrending) for a person with low coupling from spatial orientation to number ability ($\alpha_{1i} = -0.017$; Panel A), and for a person with higher coupling ($\alpha_{1i} = 1.835$; Panel B). The parameter estimate α_{1i} was computed as the sum of the population estimate γ_{10} and the person-specific deviation u_{1i}. Between-person differences in rates of change (i.e., u_{2i} and u_{3i}) were not modeled due to the relatively low number of observations per participant. Acknowledging that missing at random assumptions (Little & Rubin, 1987) are embedded in the accelerated longitudinal design even after the detrending procedures, the continuity of change in coupling across persons (with overlapping repeated measures) uses some between-person information to make inferences about within-person age-related cognitive dedifferentiation. A parallel set of models with *time-to-death* and *time-to-death*^{2} was used to examine dedifferentiation in relation to mortality.

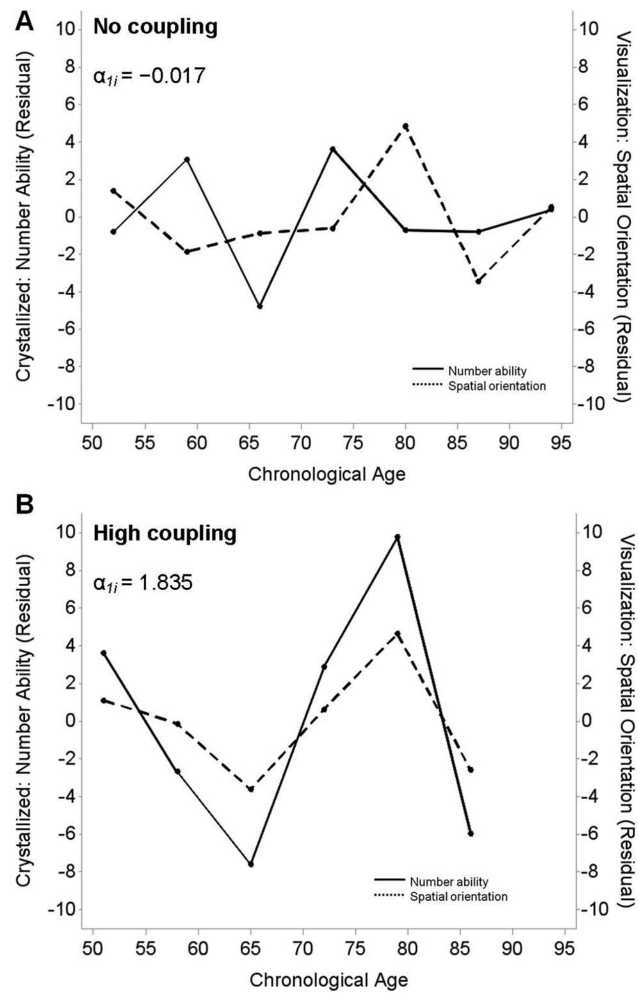

Figure 2. Detrended trajectories of number ability (crystallized) and spatial orientation (visualization) for two individuals with no ($\alpha_{1i} = -0.017$; Panel A) and higher levels ($\alpha_{1i} = 1.835$; Panel B) of coupling from spatial orientation to number ability.

Results

Cognitive Dedifferentiation Across Chronological Age

Table 2 presents results from the models examining how within-person couplings between cognitive abilities changed with age. The average coupling parameter γ_{10} indicates the extent to which the repeated measures of one cognitive ability are coupled with (can be predicted by) the other. To illustrate, the positive coupling of spatial orientation with number ability for the typical individual at age 82.52 years (see Table 2, lower quadrants) means that when spatial orientation was one unit higher than expected (based on his or her long-term trend), the number ability was also $\gamma_{10} = 0.264$ units higher than expected (based on his or her long-term trend). Findings from the model where number ability predicts spatial orientation can be found in the upper quadrants of the three panels in Table 2. Looking in the top panel of Table 2 across the γ_{10} parameters for the age-based models, 15 out of 20 coupling parameters were reliably different from 0 at $p < .05$ and positive (range = 0.145 to 0.363), indicating a positive manifold across cognitive abilities at the centering point of 82.52 years.

The linear change parameters γ_{20} indicate rate of age-related linear change in the coupling between pairs of abilities. For example, in the model where spatial orientation predicts number ability, the linear change parameter amounts to $\gamma_{20} = 0.139$ units per decade, indicating an age-related linear increase in the coupling of these two abilities. That is, the coupling parameter at the

Table 2
Overview of Coupling Parameters for Crystallized (C), Fluid (F), and Visualization (V) Abilities and Their Age-Related Linear and Quadratic Changes

	→Number	→Verbal	→Fluency	→Reasoning	→Spatial
			Coupling parameter γ_{10} (SE)		
C: Number→	—	0.244* (0.061)	0.172* (0.066)	0.182* (0.053)	0.217* (0.064)
C: Verbal→	0.156* (0.065)	—	0.226* (0.066)	0.250* (0.054)	0.161* (0.068)
C: Fluency→	0.176* (0.060)	0.147* (0.058)	—	0.058 (0.052)	−0.013 (0.063)
F: Reasoning→	0.283* (0.077)	0.363* (0.073)	0.044 (0.080)	—	0.151 (0.082)
V: Spatial→	0.264* (0.065)	0.277* (0.061)	0.009 (0.068)	0.145* (0.055)	—
			Linear change in the coupling parameter γ_{20} (SE)		
C: Number→	—	0.087* (0.041)	0.205* (0.047)	−0.005 (0.038)	0.081 (0.048)
C: Verbal→	0.062 (0.048)	—	0.054 (0.051)	0.094* (0.041)	0.050 (0.050)
C: Fluency→	0.193* (0.044)	0.056 (0.040)	—	0.026 (0.037)	0.009 (0.046)
F: Reasoning→	0.031 (0.062)	0.156* (0.056)	0.056 (0.065)	—	0.156* (0.062)
V: Spatial→	0.139* (0.051)	0.167* (0.049)	0.033 (0.054)	0.137* (0.044)	—
			Quadratic change in the coupling parameter γ_{30} (SE)		
C: Number→	—	0.009 (0.010)	0.041* (0.011)	−0.011 (0.009)	−0.001 (0.011)
C: Verbal→	0.017 (0.012)	—	0.009 (0.013)	0.011 (0.010)	0.006 (0.013)
C: Fluency→	0.035* (0.010)	0.006 (0.009)	—	0.002 (0.008)	0.005 (0.010)
F: Reasoning→	−0.003 (0.014)	0.018 (0.013)	0.016 (0.015)	—	0.026 (0.014)
V: Spatial→	0.018 (0.011)	0.025* (0.011)	0.017 (0.012)	0.025* (0.010)	—

Note. $N = 419$. Scores standardized to a T metric ($M = 50$, $SD = 10$) based on first occasion scores across the entire SLS sample. Unstandardized estimates are presented. Standard errors in parentheses. Age was centered at 82.52 years and scaled in decades to facilitate interpretation of model parameters. Rows indicate the predictors and columns indicate the criterion. In these models, each ability predicted and was predicted by all other abilities. For example, findings from the model where number ability predicted verbal meaning can be found in the upper quadrant and findings from the model where verbal meaning predicted number ability can be found in the lower quadrant. γ_{10} parameters indicate the extent to which the criterion can be predicted from the predictor. γ_{20} and γ_{30} parameters indicate rate of linear and quadratic change per decade of age.
* $p < .05$.

centering age of 82.52 years ($\gamma_{10} = 0.264$, see previous paragraph) to 0.403 over a decade at age 92.52 years (not accounting for quadratic trends). At the age of 92.52 years, when a participant's spatial orientation was one unit higher than expected (based on his or her long-term trend), his or her number ability was $\gamma_{10} = 0.403$ units higher than expected (based on his or her long-term trend). As the scores were T-standardized ($M = 50$; $SD = 10$) with first occasion scores as reference, one T score unit corresponds to a tenth of a between-person *SD* unit. This increase provides a piece of evidence in support of the age-related dedifferentiation hypothesis. In line with the hypothesis, 9 out of 20 linear change parameters (γ_{20}) were positive and reliably different from 0 at $p < .05$. The quadratic change parameter γ_{30} indicates the extent of acceleration in age-related change in coupling between ability pairs. For example, the quadratic increase in the coupling parameter for the model where spatial orientation predicts number ability was $\gamma_{30} = 0.018$. After taking the quadratic effects into account, a participant's average rate of coupling would rise from 0.264 at age 82.52 years to 0.421 at age 92.52 years. In line with the dedifferentiation hypothesis, four out of these 20 quadratic change parameters (γ_{30}) were positive and reliably different from 0 at $p < .05$, indicating accelerated increase in the coupling between abilities with age.

The implied trajectories of coupling parameters across chronological age are summarized in Figure 3. To illustrate, following the line marked by solid circles in Panel E, we see that for the average person at age 60, unit increases in spatial orientation are coupled with .04 unit increases in number ability. By age 80, unit increases in spatial orientation are coupled with .23 unit increases in number ability. The increase in this coupling estimate indicates dedifferentiation with age. Furthermore, it can be obtained from Figure 3 that the coupling effects did not change uniformly across the age range, and that the amount of dedifferentiation varied according to age. Thus, it is important to note that the dedifferentiation effects reported here are those obtained at age 82.52 years. If we had chosen to center the chronological age variable differently (e.g., at age 60), we would have found different estimates for the coupling parameters as well as for linear and quadratic increases in the coupling parameters. How the coupling parameter changes across the ages of 60 to 90 years is shown in Figure 3. Across the plots, three major patterns emerge. First, as can be seen in Panel E of Figure 3, crystallized and fluid abilities became increasingly predictable by visualization ability with age: Age-related increases were found for the couplings from visualization ability (spatial orientation) to the crystallized abilities of number and verbal meaning and to fluid ability (inductive reasoning). Spatial orientation became increasingly predictable by fluid ability as well (see Figure 3, Panel D). Second, there was also some evidence for dedifferentiation within the crystallized domain. For example, number ability became increasingly predictable by word fluency across age (see Figure 3, Panel C) and vice versa (see Figure 3, Panel A). Third, the coupling from fluid ability as indicated by reasoning to the crystallized ability of verbal meaning also increased with age (see Figure 3, Panel D). As well, the coupling from verbal meaning to inductive reasoning increased with age (see Figure 3, Panel B). Follow-up analyses excluding the subsample of participants who developed dementia during the course

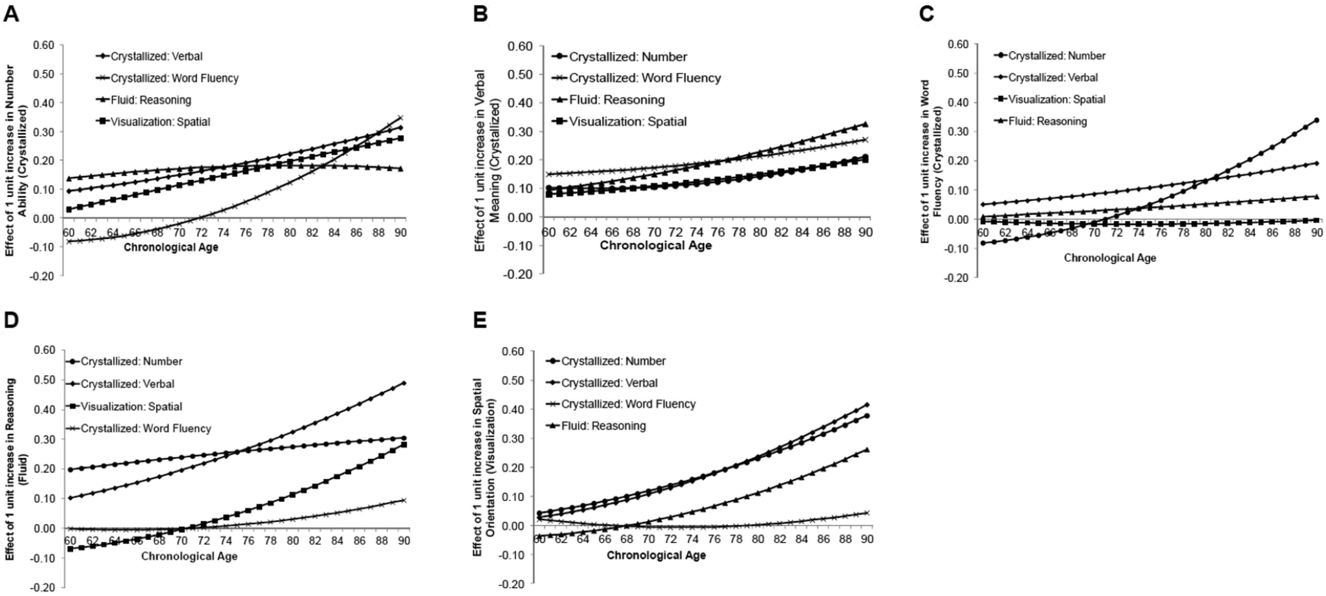

Figure 3. Coupling parameters (β_{0i}) across chronological age: Effects of one unit increase of one ability on other abilities and age-related trajectories of these effects. The dedifferentiation hypothesis predicts an increase of the coupling parameter with chronological age.

of the study revealed the same pattern of findings. In sum, looking across all models we see some support for age-related dedifferentiation, and very little evidence for the opposite.

Cognitive Dedifferentiation Across Time to Death

Table 3 presents results from the models examining how within-person couplings between cognitive abilities changed with time to death. Parameters are interpreted as they were in the age model. For example, the positive coupling of spatial orientation with number ability (for the typical individual at 2 years before death) means that when spatial orientation was one unit higher than expected, the number ability was also $\gamma_{10} = 0.369$ units higher than expected. Looking across the γ_{10} parameters for the age-based models in the time-to-death top panel of Table 3, 17 out of 20 coupling parameters were positive (range = 0.144 to 0.430) and reliably different from 0. Examining linear mortality-related change parameters (γ_{20}) in the middle right panel, 11 out of 20 parameters were positive and reliably different from 0. Similarly for the quadratic change (γ_{30}), 8 of 20 quadratic change parameters were positive and reliably different from 0. Taken together, the results provide some evidence for mortality-related dedifferentiation.

The implied trajectories of coupling parameters across time to death are summarized in Figure 4. For example, following the line marked by solid circles in Panel E, we see that for the average person at 30 years prior to death, spatial orientation is not coupled with number ability. However, in the final year, unit increases in spatial orientation are coupled with .42 unit increases in number ability. The 30 year progression indicates the extent of mortality-related dedifferentiation. Three major patterns emerged in the plots. First, as can be seen in Panel E of Figure 4, the couplings from visualization ability (spatial orientation) to crystallized ability (number ability, word fluency, verbal meaning) and fluid ability (inductive reasoning) increased across time-to death. Figure 4 also shows that the coupling from crystallized ability (number: Panel A) and from fluid ability (inductive reasoning: Panel D) to visualization ability increased as well. Second, the crystallized domain again showed some evidence for dedifferentiation: For example, word fluency became increasingly predictable by number ability across time to death (see Figure 4, Panel A) and vice versa (see Figure 4, Panel C). Third, the coupling from fluid ability as indicated by reasoning to the crystallized ability of word fluency also increased with increasing proximity of death (see Figure 4, Panel D). As well, the coupling from word fluency to inductive reasoning increased with increasing proximity of death (see Figure 4, Panel B). Follow-up analyses excluding the subsample of participants who developed dementia during the course of the study revealed the same pattern of findings.

Discussion

Our goal in the present study was to examine cognitive dedifferentiation with increasing age and proximity to death from a within-person perspective. To do so, we used longitudinal data from the SLS wherein five cognitive abilities were measured on up to eight measurement occasions over up to 49 years, thus covering the adult life span from early adulthood to very old age. Our findings provided some evidence for cognitive dedifferentiation across chronological age and time to death. Specifically, our results suggest an increase in the within-person couplings (a) among the crystallized abilities, (b) between visualization ability and fluid ability, (c) between visualization ability and crystallized ability, and (d) between fluid ability and crystallized ability, both over age and time to death. There was support for both age-related and mortality-related dedifferentiation. Although fewer significant

Table 3
Overview of Coupling Parameters for Crystallized (C), Fluid (F), and Visualization (V) Abilities and Their Time-to-Death Related Linear and Quadratic Changes

	→Number	→Verbal	→Fluency	→Reasoning	→Spatial
			Coupling parameter γ_{10} (SE)		
C: Number→	—	0.210* (0.078)	0.277* (0.087)	0.282* (0.069)	0.357* (0.086)
C: Verbal→	0.234* (0.089)	—	0.262* (0.093)	0.230* (0.075)	0.271* (0.093)
C: Fluency→	0.179* (0.078)	0.194* (0.073)	—	0.144* (0.066)	0.083 (0.081)
F: Reasoning→	0.430* (0.100)	0.321* (0.093)	0.189 (0.104)	—	0.277* (0.103)
V: Spatial→	0.369* (0.080)	0.317* (0.076)	0.142 (0.085)	0.170* (0.068)	—
			Linear change in the coupling parameter γ_{20} (SE)		
C: Number→	—	0.026 (0.064)	0.272* (0.073)	0.104 (0.059)	0.237* (0.074)
C: Verbal→	0.107 (0.081)	—	0.074 (0.085)	0.046 (0.068)	0.148 (0.083)
C: Fluency→	0.167* (0.064)	0.100 (0.059)	—	0.115* (0.054)	0.101 (0.067)
F: Reasoning→	0.171* (0.086)	0.091 (0.078)	0.194* (0.090)	—	0.284* (0.086)
V: Spatial→	0.245* (0.067)	0.183* (0.065)	0.157* (0.072)	0.144* (0.058)	—
			Quadratic change in the coupling parameter γ_{30} (SE)		
C: Number→	—	−0.007 (0.014)	0.050* (0.016)	0.012 (0.013)	0.033* (0.016)
C: Verbal→	0.020 (0.019)	—	0.010 (0.020)	−0.002 (0.016)	0.024 (0.019)
C: Fluency→	0.027* (0.014)	0.014 (0.012)	—	0.021 (0.011)	0.023 (0.014)
F: Reasoning→	0.024 (0.019)	0.003 (0.017)	0.043* (0.020)	—	0.055* (0.019)
V: Spatial→	0.041* (0.014)	0.025 (0.014)	0.040* (0.015)	0.025* (0.012)	—

Note. $N = 419$. Scores standardized to a T metric ($M = 50$, $SD = 10$) based on first occasion scores across the entire SLS sample. Unstandardized estimates are presented. Standard errors in parentheses. Time to death was centered at 2 years prior to death and scaled in decades to facilitate interpretation of model parameters. Rows indicate the predictors and columns indicate the criterion. In these models, each ability predicted and was predicted by all other abilities. For example, findings from the model where number ability predicted verbal meaning can be found in the upper quadrant and findings from the model where verbal meaning predicted number ability can be found in the lower quadrant. γ_{10} parameters indicate the extent to which the criterion can be predicted from the predictor. γ_{20} and γ_{30} parameters indicate rate of linear and quadratic change per decade of time-to-death.
* $p < .05$.

findings were found for age as compared to time to death, the age and time-to-death parameters had overlapping confidence intervals. In sum, the general pattern of age- and mortality-related declines in individuals' cognitive abilities reported widely in the literature, is complemented by evidence of a pattern of within-person dedifferentiation in the structural organization of cognitive abilities.

Cognitive Dedifferentiation Across Age From a Within-Person Approach

The present study adds to the cognitive dedifferentiation literature by showing some longitudinal evidence for cognitive dedifferentiation across age from a within-person change perspective. In previous studies, between-person information has been used as proxy for within-person information. However, between-person examinations of age-related cognitive dedifferentiation may not necessarily lead to similar findings as within-person examinations (Molenaar & Campbell, 2009). For example, at the between-person level, some older adults might show steeper age-related declines in both fluid and crystallized abilities than their peers, because for them age-related decline in cognition might have started at an earlier age than for their peers. When examining rates of cognitive change in young adults, one might not observe such a pattern. In such a scenario, one would find evidence for dedifferentiation between fluid and crystallized abilities, because changes in these abilities would be more strongly related for older individuals. However, this does not necessarily mean that the same pattern of findings will emerge at the within-person level. For example, less efficient functioning in the fluid domain on one occasion may not necessarily affect the performance on all crystallized tests at the same occasion. In this scenario, evidence for dedifferentiation would be weaker at the within-person level as compared to the between-person level.

It is likely that the similarity of within-person and between-person structures differs by age. In older adults, cognitive changes can be simultaneously caused by mechanisms related to age, pathology, and mortality (e.g., Ghisletta, McArdle, & Lindenberger, 2006; Sliwinski, Lipton, Buschke, & Stewart, 1996). Due to these various influences in old age, the similarity of between-person and within-person structure might be lower than at younger ages. Thus, in studies examining the structure of abilities or behavior across a large range of ages and possible birth cohorts, it is instrumental to separate between-person and within-person change to control for potential confounds.

Cognitive Dedifferentiation Across Time to Death

Extending previous work on mortality-related cognitive dedifferentiation with a longitudinal within-person examination of this hypothesis, we found some evidence of cognitive dedifferentiation as individuals moved closer to death. Recent evidence has shown that time to death accounted for more variance in between-person differences in late-life change (Fauth, Gerstorf, Ram, & Malmberg, 2014; Gerstorf, Ram, Lindenberger, & Smith, 2013; Ram et al., 2010). It is still a largely unanswered question whether the

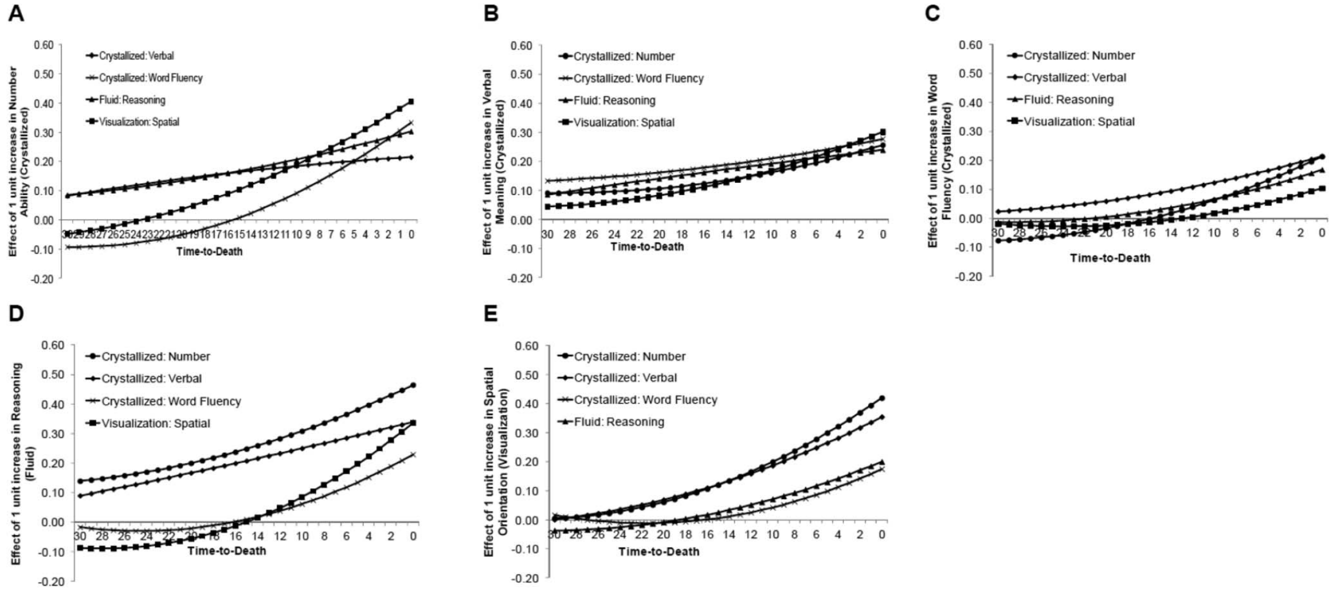

Figure 4. Coupling parameters (β_{0i}) across time to death. Effects of one unit increase of one ability on other abilities and time-to-death trajectories of these effects. The notion of terminal dedifferentiation implies an increase of the coupling parameter with proximity of death.

typically observed steep declines in cognitive performance close to death (i.e., terminal decline) are accompanied by a dedifferentiation of the ability structure. The present study provides initial evidence from a within-person perspective that mortality-related processes do shape level, changes, and the structural organization of some cognitive abilities. Based on previous research showing considerably stronger rates of cognitive decline over time to death as compared to age, we expected mortality-related cognitive dedifferentiation to be stronger than dedifferentiation over age. However, our findings showed that evidence for cognitive dedifferentiation was comparably strong across both age and time to death. Because of the 7-year intervals between data collections, we were not able to focus our analyses on cognitive dedifferentiation in the very last years of life, where mortality-related dedifferentiation might accelerate particularly rapidly. Future studies can examine whether dedifferentiation is stronger across time-to-death as compared to age in the terminal phase characterized by precipitous cognitive declines.

The compression of the ability structure in old age has implications for diagnosis. Brief tests of cognitive ability focusing on one ability dimension may be more or less indicative of function across multiple domains depending on the individual's age and pathology. The finding that some of the couplings among cognitive abilities increase with age and time to death suggests that observed deficits in one domain are likely to generalize to other domains when an individual is older and/or closer to death, while having less of an impact on other domains when the individual is younger.

Limitations and Outlook

The benefit of the SLS study design is that the individual-level time-series spans a substantial duration of the adult life span. The limitation of the design is that there are only up to eight occasion time-series available for quantification of coupling. Thus, we (like other studies) had to rely on the accelerated longitudinal design and the assumptions embedded regarding partial convergence of within-person and between-person information within it. One limitation results from longitudinal missing at random assumptions. Not all individuals have been examined at all ages; these data are, however, not missing entirely at random, but due to differing birth cohorts and due to mortality. From a within-person perspective, age and mortality-related change are perfectly correlated (e.g., as an individual ages by 1 year, he or she also comes 1 year closer to death). In the present study, we had to rely on age and time to death—which are not pure within-person predictors—as proxies for long-term developmental processes (see Ram et al., 2010). Still, the present study is closer to examining dedifferentiation from a within-person perspective than any previous study to our knowledge. The design of the SLS affords the possibility to use such a framework and take a within-person approach (however, see reliability concerns noted in Mejía, Hooker, Ram, Pham, & Metoyer, 2014). The ideal study would include intensive multivariate longitudinal data obtained continuously for decades that would be analyzed using person-specific P-technique factor analytical methods (see Brose & Ram, 2012). Also, having only between four and eight observations for each individual constrained our ability to fully capture more complex patterns of change. For example, use of multiphase models to identify the exact age or time to death at which cognitive dedifferentiation began would likely be beyond the data (see. however, Fauth et al., 2014). Studies identifying specific points of transition can be useful for a more precise description of structural changes in cognitive ability. With regard to mortality-related cognitive changes, previous research indicates that precipitous declines set in approximately 2.5 to 6 years before death (Wilson et al., 2003, 2007; Wilson, Segawa, Buchman et al., 2012; Wilson, Segawa, Hizel et al., 2012). Study designs including more closely spaced assessments during the terminal decline period can offer insights into the time course of terminal dedifferentiation in cognitive abilities. Also, the onset of dedifferentiation might differ by the set of cognitive abilities examined. For example, fluid abilities typically decline earlier than crystallized abilities (see Schaie, 2013). These differences in the timing of cognitive decline could have an effect on trajectories of dedifferentiation as well.

In our analyses of age- and time-to-death-related cognitive dedifferentiation, we started with cognitive ability scores obtained on eight measurement occasions at 7-year intervals over up to 49 years. Following the time-series literature (e.g., Shumway & Stoffer, 2006) we preprocessed the data, detrending each individual's repeated measures using additive polynomials, to obtain residual scores that could, following the multilevel modeling literature (e.g., Snijders & Bosker, 1999), be analyzed for patterns of within-person covariation. Depending on perspective, the detrended scores are considered as observed differences between observed data and an (observable) estimated function value (i.e., as residuals) or as observed differences between observed data and a (unobservable) true function value (i.e., as errors). On the one hand, the detrending step serves a measurement function, and the residual scores are analogous to calculated scale scores. In the time-series and econometrics literature it is generally accepted that detrending improves the performance of (stationarity assuming) modeling methods (Shumway & Stoffer, 2006). Viewed from this perspective our preprocessing/detrending step is viewed as data cleaning preparation for a single analysis. On the other hand, the detrending model serves a statistical inference function, and the error scores are analogous to estimated latent factor scores. In the regression and multilevel modeling literature it is well known that treating estimated scores as input into regression models biases the standard errors because their calculation does not account for the standard errors that are associated with the estimated score inputs (Snijders & Bosker, 1999). Viewed from this perspective, our analysis is a 2-step analysis where the detrending model produced estimated scores that were then used in a multilevel regression model, and inferences based on the standard errors should be done cautiously. Outside of the philosophical differences between the time-series and multilevel regression approaches we have attempted to merge together in this analysis, our own concerns about the substantive inference are alleviated by the congruence we see across analyses. Admittedly, in trying to construct practically viable tests of a within-person theory of dedifferentiation we are asking a unique data set to help answer questions that it was not specifically designed to test. More ideal, from both time-series and multilevel modeling perspectives, would be intensive longitudinal data streams that allow for even better continuity across data treatments, modeling approaches, and time (e.g., hundreds of observations obtained continuously over the entire adult life span).

As longitudinal markers of cognitive ability, five subtests from the 1948 PMA 11–17 version of Thurstone's Primary Mental Abilities Test (Thurstone & Thurstone, 1949) have been used in the SLS—which had been established prior to the popularity of the two-factor model of fluid and crystallized intelligence (Cattell, 1963). Future studies might seek to replicate the present findings with a wider set of measures drawn from gf/gc models of the structure of cognitive abilities. In the present study, our measures included only one test of fluid ability. We found that the crystallized ability of verbal meaning became increasingly predictable by this fluid ability measure across age. However, this was not the case for the other two crystallized abilities of number ability and word fluency. It is possible that performance on these tests relates to other aspects of fluid ability that were not measured in the present study. Verbal ability is generally considered the strongest marker of crystallized ability. Also, the PMA verbal meaning and number tests are highly speeded compared to other tests of vocabulary or number (see Hertzog, 1989; Schaie, 2013). Future research should examine whether the increase in the couplings from fluid to crystallized intelligence generalizes across more comprehensive measures.

The present analyses indicated that the average coupling varies across (pairs of) cognitive abilities over age (range $= -0.013$ to 0.363) and time to death (range $= 0.083$ to 0.430) and that the coupling increases by about 0.10 to 0.20 per decade. Currently, there are no theoretical accounts of the extent of coupling that can be expected for each set of cognitive measures, or the extent of coupling that indicates a dedifferentiated structure. This represents a new layer of precision that now needs to be defined, so that we can track how individuals move from a qualitatively "differentiated" organization to a qualitatively "dedifferentiated" organization. In a common factor-modeling framework, a statistical test could be performed to see if fewer factors were needed, which would provide evidence for dedifferentiation (see P-technique tests in Ram, Rabbitt, Stollery, & Nesselroade, 2005).

The present study is a first descriptive step toward establishing within-person approaches to the study of dedifferentiation. We did not examine possible reasons for dedifferentiation, such as the decline of sensory, motor, and CNS functions in old age that have been proposed as potential causes of cognitive dedifferentiation. This was due to a lack of measures that would be available in a consistent fashion across the 49 years. Because of declines in sensory, motor, and CNS functions, individual differences in cognitive abilities may increasingly depend on the physiological infrastructure (Schaie, 1962; Schaie et al., 2000). For example, previous research has shown that sensory functioning (visual and auditory acuity) is related to both fluid and crystallized ability (Lindenberger & Ghisletta, 2009). Future studies should examine the role of sensory and physiological functioning in cognitive dedifferentiation. Another explanation for age-related dedifferentiation is that age-related decline processes constrain cognitive processes constituting broader cognitive abilities and compress their structure (Li et al., 2004). This hypothesis should also be tested in future studies.

Lastly, the participants of the present study were positively biased in terms of years of formal education and age at death (see Table 1), given the geographic location of the sample and long-term involvement in the SLS. Participants in the SLS were reasonably healthy community-dwelling individuals representing the upper 75% of the Seattle metropolitan area in terms of socioeconomic criteria (Schaie, 2013). It would thus be instructive to examine whether the evidence for within-person cognitive dedifferentiation reported in the present study also generalizes to more heterogeneous populations. It is an open question whether age-related dedifferentiation is comparable across different levels of ability. Previous research has shown that cognitive abilities have a more differentiated structure among those with higher levels of cognitive abilities, termed "ability differentiation" (e.g., Abad, Colom, Juan-Espinosa, & Garcia, 2003; Tucker-Drob, 2009). Based on this notion, it may be expected that age and mortality-related dedifferentiation would be stronger in less positively selected populations. That we found evidence for cognitive dedifferentiation in such a positively selected sample suggests that these effects would probably be even stronger with more heterogeneous samples. Also, the participants in our sample belonged to different birth year cohorts. Previous reports from the SLS showed lower scores for number ability in cohorts born after 1924 (Schaie, 2013), possibly due to differences in mathematics education. It is possible that such differences not only affect performance levels, but also within-person covariances among cognitive abilities. Future studies can examine how this relates to age-related dedifferentiation in samples that span across a wide range of cohorts.

Conclusions

This study adds to previous work on structural changes in cognitive abilities across the life span by examining cognitive dedifferentiation from a within-person perspective. Our findings support the age-related cognitive dedifferentiation hypothesis by showing age-related increases in average within-person coupling between pairs of cognitive abilities and providing initial longitudinal evidence for within-person cognitive dedifferentiation as individuals get closer to death. Further research is needed to understand how individuals transition from a differentiated to a dedifferentiated cognitive structure and the mechanisms leading to such a transition.

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