Cognitive development across the lifespan: Conceptual, methodological and analytical challenges of a lifespan approach

Part 1

Paolo Ghisletta
University of Geneva
ISSBD Workshop, Sept 3 2015

General Outline

1. Classical vs. contemporary developmental research
2. Lifespan development
3. Longitudinal methodology
4. Meaning of "age"
5. Latent variable models of change
6. Linear latent curve models and linear mixed-effects models
7. Nonlinear mixed-effects models

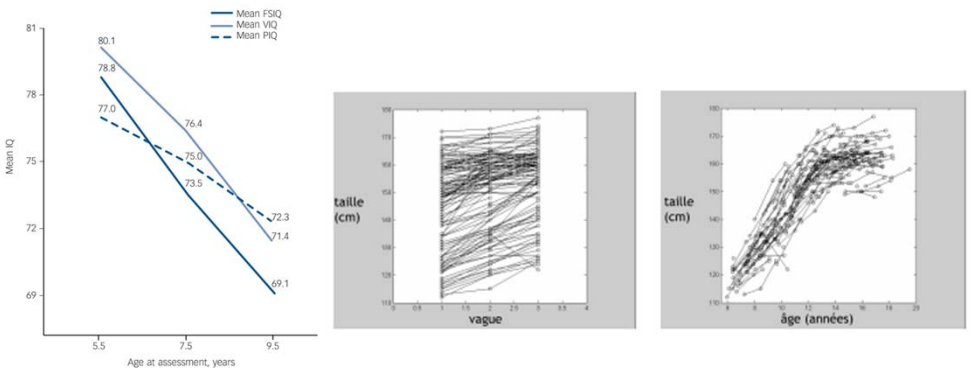
1. Classical vs. Contemporary

Assess interindividual differences to approximate intraindividual changes

Contributions from interindividual differences psychology to the study of development **(Cronbach, 1957; Baltes, 1987; Baltes & Nesselroade, 1979; de Ribaupierre, 2003)**

- **Focus on individuals and processes, not on variables or functions**
- **Focus on variability (interindividual and intraindividual)**
- **Major interest for methods and statistical models, especially multivariate**
- **Use of multivariate data collection designs**

Interindividual Differences vs. Intraindividual Changes



Interindividual Differences vs. Intraindividual Changes

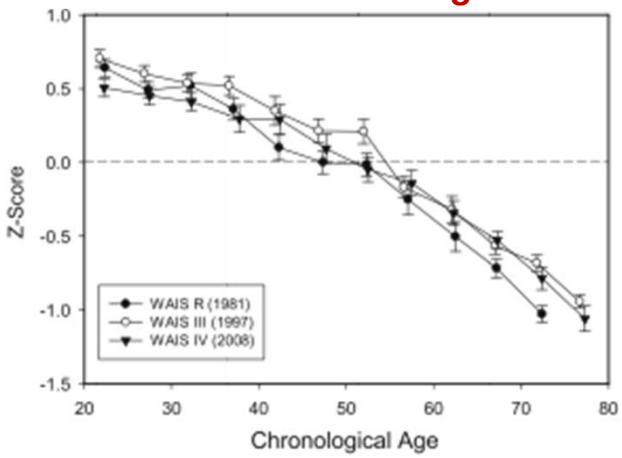


Fig. 1 Means (and standard errors) of sample-specific *z* scores as a function of age on the Digit Symbol Coding Test in nationally representative samples at three different time periods

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Interindividual Differences vs. Intraindividual Changes

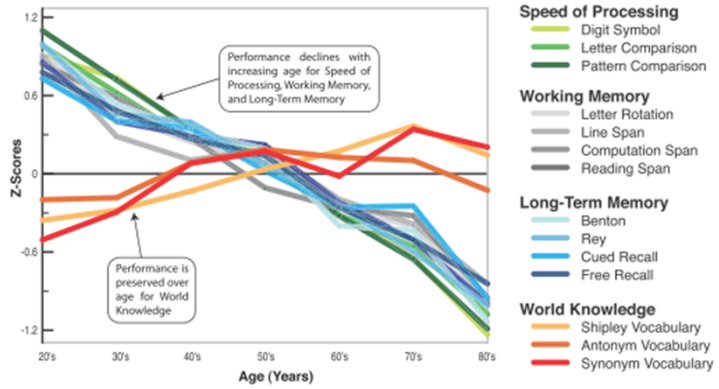

Figure 1

Cross-sectional aging data adapted from Park et al. (2002) showing behavioral performance on measures of speed of processing, working memory, long-term memory, and world knowledge. Almost all measures of cognitive function show decline with age, except world knowledge, which may even show some improvement.

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Interindividual Differences vs. Intraindividual Changes

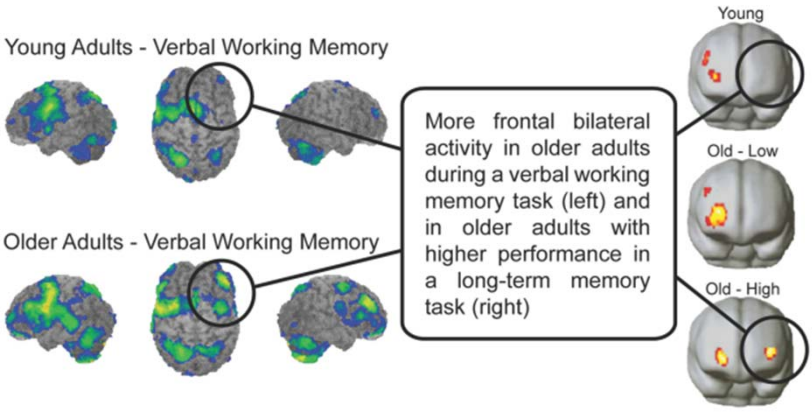

Figure 3

Frontal bilaterality is increased with age. (*Left side*) Left lateralized frontal engagement in young adults during a verbal working memory task; in older adults, an additional right frontal engagement is observed (adapted from Reuter-Lorenz et al. 2000). (*Right side*) Right lateralized engagement in young adults and low-performing older adults during a long-term memory task, and bilateral frontal engagement in high-performing older adults (adapted from Cabeza et al. 2002).

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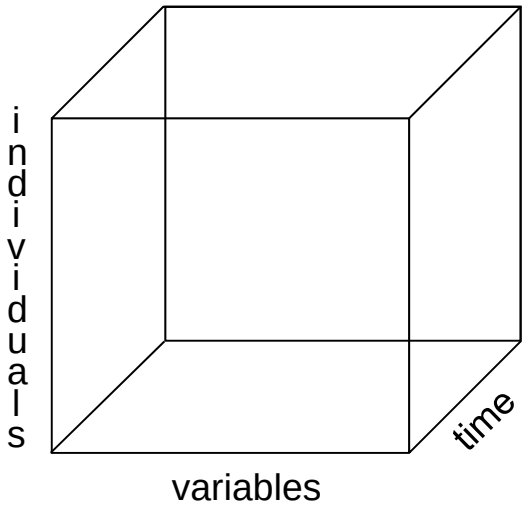
Cattell's Data Box



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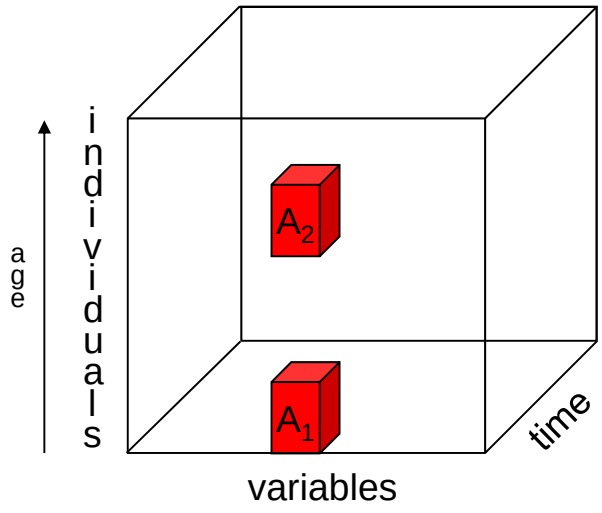
Cattell's Data Box: Classical Developmental Study



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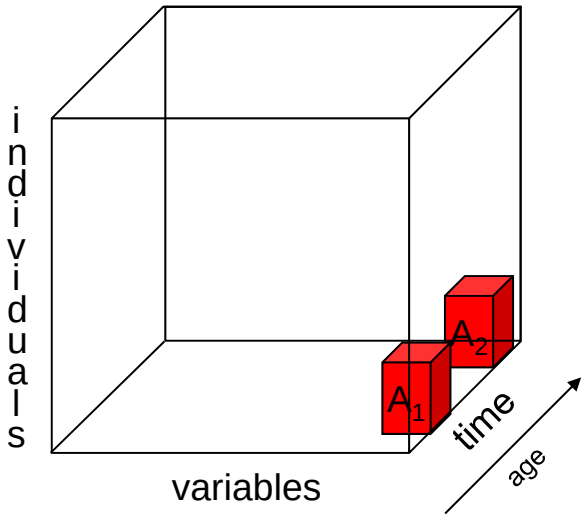
Cattell's Data Box: "Ideal" Developmental Study



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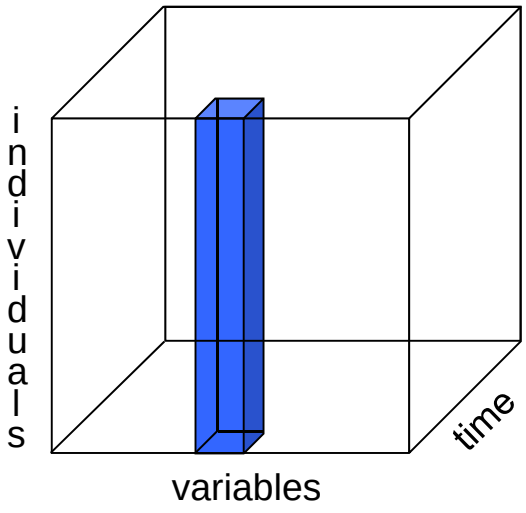
Cattell's Data Box: Individual Differences Psychology



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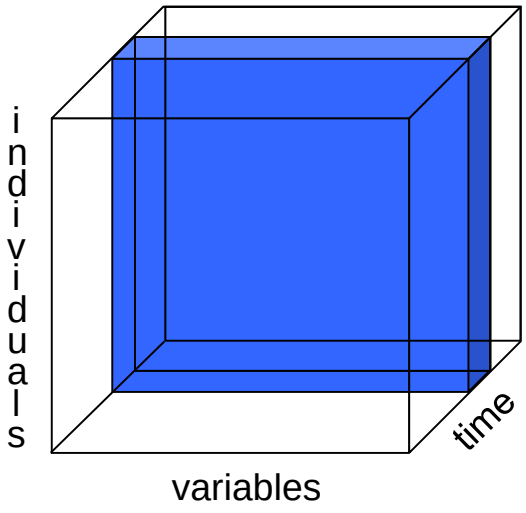
Cattell's Data Box: Individual Differences Psychology



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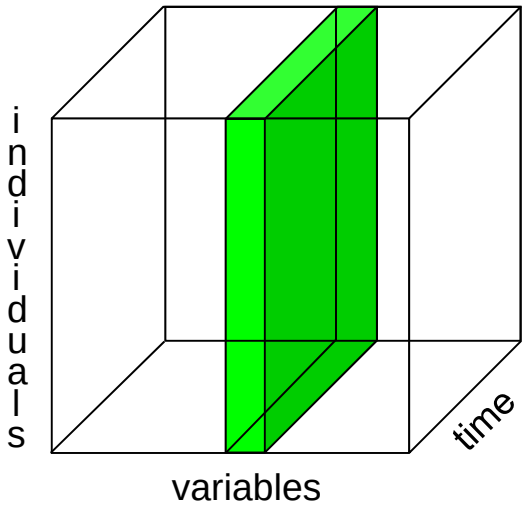
Cattell's Data Box: Individual Differences Developmental Psychology



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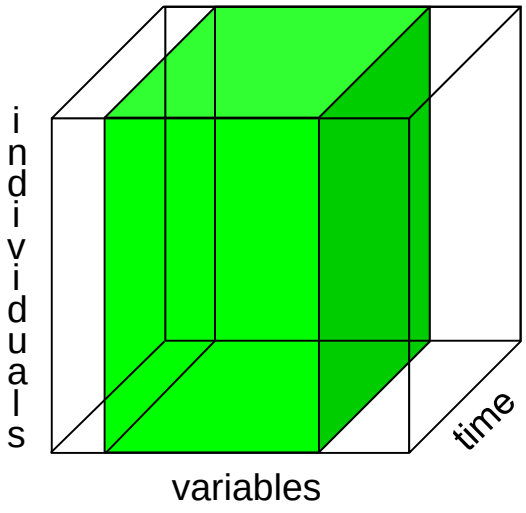
Cattell's Data Box: Individual Differences Developmental Psychology



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1. Classical vs. Contemporary: Conclusions

Cognitive aging is the field that most successfully implements methodological convergence (Schaie, Baltes)

French-speaking individual-differences psychologists in child development (Reuchlin, Lautrey, de Ribaupierre)

Developmental studies necessitate longitudinal methodologies

Methodological expertise is required in developmental psychology

The lifespan approach best reunites individual-difference approach and developmental psychology. Deep comprehension of the age variable and of longitudinal methodologies is necessary.

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2. Lifespan Development

Baltes, P. B. (1987). Theoretical propositions of life-span developmental psychology :On the dynamics between growth and decline. *Developmental Psychology, 23*, 611-626

"Life-span developmental psychology involves the study of constancy and change in behavior throughout the life course (ontogenesis), from conception to death. The goal is to obtain knowledge about general principles of life-long development, about interindividual differences and similarities in development, as well as about the degree and conditions of individual plasticity or modifiability of development." (p. 611)

"The most general orientation toward this subject matter is simply to view behavioral development as a lifelong process." (p. 612)

For many researchers, the life-span orientation entails several prototypical beliefs that, in their weighting and coordination, form a family of perspectives that together specify a coherent metatheoretical view on the nature of development. (p. 612)

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Propositions of Lifespan Development

1. **Lifespan development: Ontogenetic development is a life-long process**
2. **Multidirectionality: Pluralism in directionality of change**
3. **Development as gain/loss: They jointly occur to shape development**
4. **Plasticity: within-person modifiability**
5. **Historical embededness: importance of historical-cultural conditions**
6. **Contextualism as paradigm: age-graded, history-graded, and nonnormative influences**
7. **Multidisciplinarity: human development not the exclusive field of developmental psychology**

Multidimensionality and Multidirectionality

Multidimensionality
Multidirectionality

Different Forms of Intelligence

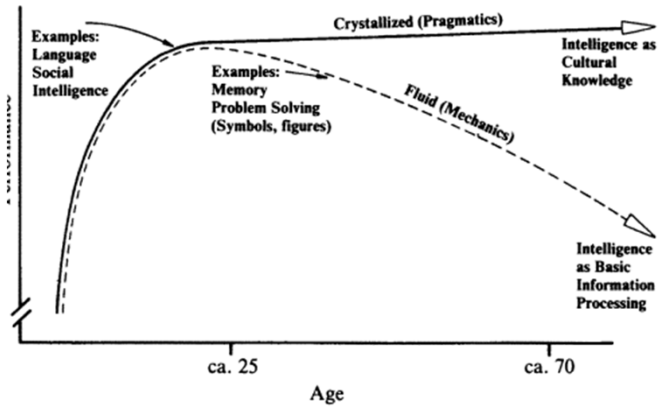

Figure 1. One of the best known psychometric structural theories of intelligence is that of Raymond B. Cattell and John L. Horn. (The two main clusters of that theory, fluid and crystallized intelligence, are postulated to display different life-span developmental trajectories.)

Dynamics between Gains and Losses

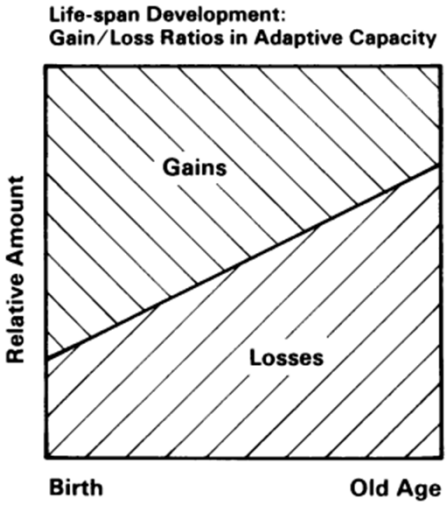

Figure 2. One theoretical expectation concerning the average course of gain/loss ratios is a proportional shift across the life span.

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Plasticity

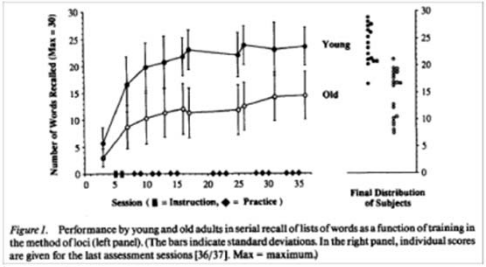

Figure 1. Performance by young and old adults in serial recall of lists of words as a function of training in the method of loci (left panel). (The bars indicate standard deviations. In the right panel, individual scores are given for the last assessment sessions [36/37]. Max = maximum.)

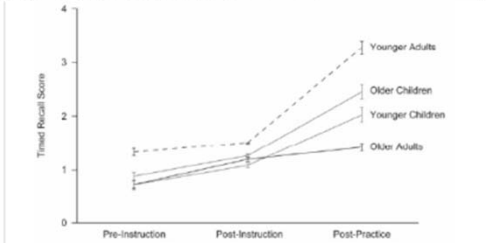

Figure 4. Life-span age differences in memory plasticity. The timed recall score is a ratio of correctly recalled items over encoding time, $ci/\ln(1 + ei/1000) \cdot (\ln 11)/10$. Postinstruction scores for younger adults cannot be interpreted because of ceiling effects; all other data points can be interpreted. Error bars represent standard errors.

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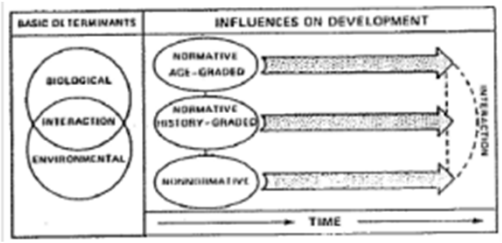
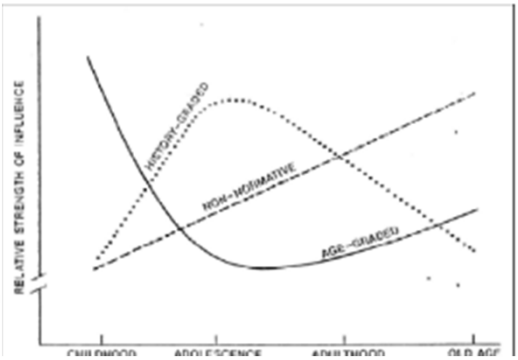
Age, history, Nonnormative Influences





3. Longitudinal Methodology

Baltes, P. B., & Nesselroade, J. R. (1979). History and rationale of longitudinal research. In J. R. Nesselroade, & P. B. Baltes (Eds.), Longitudinal research in the study of behavior and development (pp. 1-39). New York, NY : Academic Press.

“The study of phenomena in their time-related constancy and change is the aim of longitudinal methodology” (p. 2).

Different kinds: panel studies, repeated measures, single-case studies, time series, “mini-longitudinal,” “shortitudinal,” etc.

Five Objectives

1. Direct identification of intraindividual change
2. Direct identification of interindividual differences (similarity) in intraindividual change
3. Analysis of interrelationships in behavioral change
4. Analysis of causes (determinants) of intraindividual change
5. Analysis of causes (determinants) of interindividual differences in intraindividual change

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Methodological Challenges

Longitudinal studies as quasi-experimental or experimental, rather than pre-experimental

- Need for control and complex designs
- Need to vary time lags, more than 2 waves
- Simulation studies
- Multivariate approach
- Analyses must handle non-independence of observations

Some serious threats to validity

- Retest effects
- Maturation
- Historical effects
- Selection / mortality

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4. Meaning of age

Wohlwill, J. F. (1970). The age variable in psychological research. *Psychological Review, 77,* 49-64.

"For the psychologist, age shares with sex the attraction of its great visibility as a dimension of individual variation in behavior, one which is not only readily measurable but accounts for a substantial portion of variance in a variety of behavioral measures" (p. 49).

"Considering the popularity of this variable in psychological research, there has been a notable reluctance on the part of psychologists to examine the question of scientific method, inference, and theory which arise when differences in behavior are related to age" (p. 49).

Rather than IV [behavior = *f*(age)], consider age as DV

→ which characteristics determine or mediate age effects on behavior?

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Developmental Function vs. Uninteresting H_0

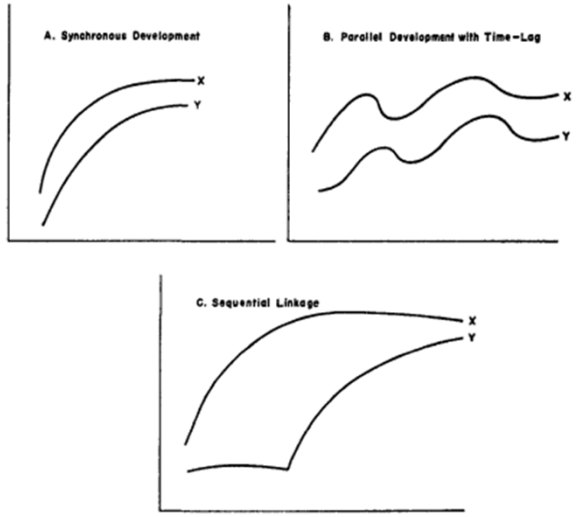

FIG. 1. Three patterns of interrelationships between variables undergoing development.

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Sliwinski et al. (2003)

Sliwinski, M. J., Hofer, S. M., Hall, C., Buschke, H., & Lipton, R. B. (2003). Modeling memory decline in older adults : The importance of preclinical dementia, attrition, and chronological age. *Psychology and Aging, 18*, 658-671.

This longitudinal study examined memory loss in a sample of 391 initially nondemented older adults. Analyses decomposed observed memory loss into decline associated with preclinical dementia, study attrition, terminal decline, and chronological age. Measuring memory as a function of only chronological age failed to provide an adequate representation of cognitive change. Disease progression accounted for virtually all of the memory loss in the 25% of the sample that developed diagnosable dementia. In the remainder of the sample, both chronological age and study attrition contributed to observed memory loss. These results suggest that much of memory loss in aging adults may be attributable to the progression of preclinical dementia and other nonnormative aging processes that are not captured by chronological age.

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Sliwinski et al. (2003)

We argue here that representing cognition as a function of chronological age can obscure identification and modeling of important causes of cognitive change, such as the progression of preclinical dementia. Alternative representations of cognitive change are required to understand such nonnormative influences on cognition. (p. 658)

Wohwill (1970, p. 49) has argued that chronological age "be incorporated into the dependent variable in developmental studies" by defining it in terms of parameters of functional change. Modern approaches to longitudinal data analyses (i.e., multilevel modeling) have in some sense met Wohlwill's demand. (p. 658)

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Sample Data

Table 2
Example (Artificial) Data for 3 Individuals

Person	Wave	Age (years)	Disease progression (years)	Memory score
1	1	67	−3.25	100.00
1	2	68	−2.25	88.50
1	3	69	−1.25	74.00
1	4	70	−0.25	56.50
1	5	71	0.75	36.00
1	6	72	1.75	12.50
2	1	55	−5.00	100.00
2	2	56	−4.00	93.50
2	3	57	−3.00	84.00
2	4	58	−2.00	71.50
2	5	59	−1.00	56.00
2	6	60	0.00	37.50

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Description of Group Differences

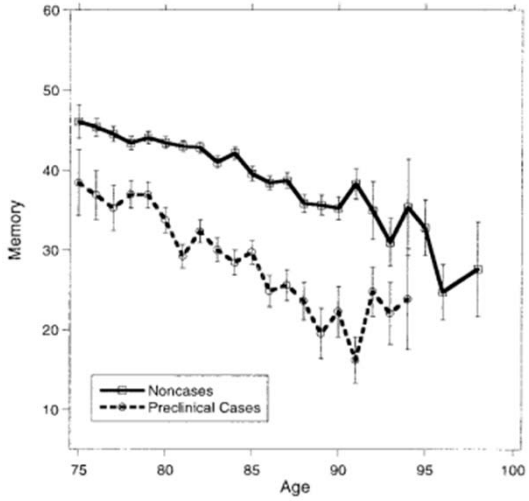

Figure 1. Mean memory scores as function of chronological age: noncase group and preclinical cases group. Bars reflect one standard error.

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Statistical Modeling

Table 1
Models of Intraindividual Change

Model	Construct	Measurement (within-person) model	Structural (between-persons) model
1	Chronological aging	$y_{ij} = \pi_{0j} + \pi_{1j}\text{Age}_{ij} + \pi_{2j}\text{Age}_{ij}^2 + r_{ij}$	$\pi_{0j} = \beta_{00} + U_{0j}$ $\pi_{1j} = \beta_{10} + U_{1j}$ $\pi_{2j} = \beta_{20} + U_{2j}$
1a	Chronological aging	$y_{ij} = \pi_{0j} + \pi_{1j}\text{Age}_{ij} + \pi_{2j}\text{Age}_{ij}^2 + r_{ij}$	$\pi_{0j} = \beta_{00} + \beta_{01}(\text{PreDx}) + U_{0j}$ $\pi_{1j} = \beta_{10} + \beta_{11}(\text{PreDx}) + U_{1j}$ $\pi_{2j} = \beta_{20} + \beta_{21}(\text{PreDx}) + U_{2j}$
2	Dementia	$y_{ij} = \pi_{0j} + \pi_{1j}\text{ToDx}_{ij} + \pi_{2j}\text{ToDx}_{ij}^2 + r_{ij}$	$\pi_{0j} = \beta_{00} + U_{0j}$ $\pi_{1j} = \beta_{10} + U_{1j}$ $\pi_{2j} = \beta_{20} + U_{2j}$
2a	Aging + dementia	$y_{ij} = \pi_{0j} + \pi_{1j}\text{Age}_{ij} + \pi_{2j}\text{Age}_{ij}^2 + \pi_{3j}\text{ToDx}_{ij} + \pi_{4j}\text{ToDx}_{ij}^2 + r_{ij}$	$\pi_{0j} = \beta_{00} + U_{0j}$, $\pi_{3j} = \beta_{30} + U_{3j}$

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Results for Entire Sample

Table 4
Fixed and Random Effects: Pooled Noncase and Preclinical Case Groups (N = 391)

	Model 1		Model 1a	
Fixed effect	Coefficient	95% CI	Coefficient	95% CI
Intercept, β_{00}	36.76	35.63, 37.88	39.93	38.75, 41.09
PreDx, β_{01}			−11.88	−14.25, −9.62
Linear age, β_{10}	−1.00	−1.18, −0.84	−0.88	−1.07, −0.69
PreDx, β_{11}			−0.26	−0.66, 0.13
Quadratic age, β_{20}	−0.031	−0.05, −0.01	−0.03	−0.06, −0.01
PreDx, β_{21}			0.020	−0.04, 0.08
−2 log-likelihood	−10,056.30		9,953.70	
BIC	10,107.30		10,026.50	

Note. Linear age = age − 85; quadratic age = (age − 85)^2. CI = confidence interval; PreDx = prediagnosis (1 if preclinical dementia, 0 otherwise); BIC = Bayesian Information Criterion.

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Results for Preclinical Cases

Table 5
Memory Change: Preclinical Case Group (n = 98)

	Model 1		Model 2		Model 2a	
Fixed effect	Coefficient	95% CI	Coefficient	95% CI	Coefficient	95% CI
Intercept	27.99	25.72, 30.26	34.67	32.85, 36.50	34.83	32.38, 37.28
Linear age	−1.21	−1.62, −0.79			0.12	−0.33, 0.57
Quadratic age	−0.03	−0.08, 0.03			0.02	−.028, 0.07
Linear ToDx			−1.58	−1.30, −1.85	−1.65	−1.27, −2.03
Quadratic ToDx			−0.11	−0.17, −0.06	−0.12	−0.17, −0.06
−2 log-likelihood	−2,289.20		−2,236.50		−2,231.20	
BIC	2,329.60		2,271.10		2,283.30	

Note. Linear age = age − 85; quadratic age = (age − 85)^2. CI = confidence interval; linear ToDx = years to diagnosis − 5; quadratic ToDx = (years to diagnosis − 5)^2; BIC = Bayesian Information Criterion.

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Expected Trajectories for Preclinical Cases

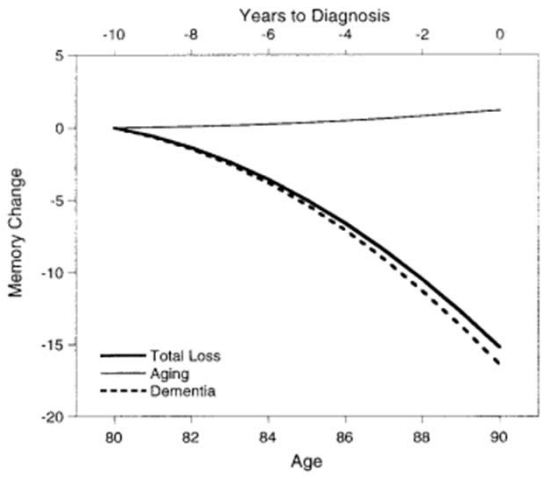

Figure 3. Component-change plot: preclinical cases group. Note that total change is the expected memory decline based on parameter estimates from the aging–dementia model in Table 5.

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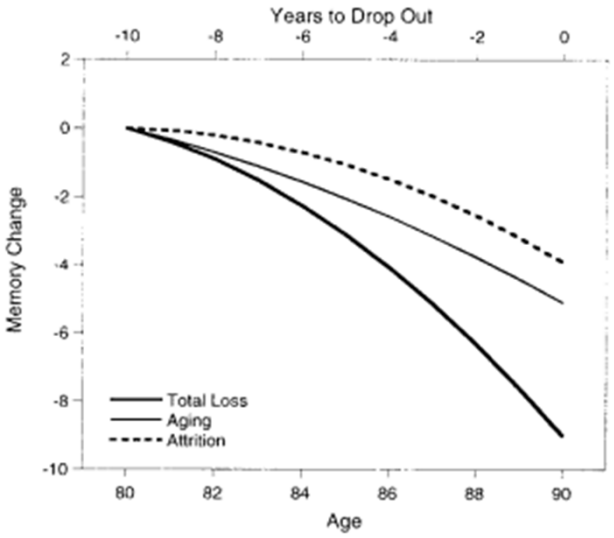
Expected Trajectories for Noncase Dropouts



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Gerstorf et al. (2013)

Gerstorf, D., Ram, N., Lindenberger, U., & Smith, J. (2013). Age and time-to-death trajectories of change in indicators of cognitive, sensory, physical, health, social, and self-related functions. *Developmental Psychology, 49*, 1805-1821.

Relatively little is known about what aspects of late-life functioning are prone to "attacks" from mortality-related processes and what factors contribute to end-of-life decline. We use longitudinal data from the Berlin Aging Study to examine the multidimensional nature of late-life change. To broadly represent central characteristics of individual functioning, we selected six domains and well-established indicators thereof from the measurement battery of the BASE. We pursue two sets of goals. First, we apply growth models to characterize late-life change trajectories in key indicators of cognitive, sensory, physical, health, social, and self-related functions across chronological age and time-to-death to determine whether mortality-related processes do indeed generalize across multiple domains of function. Second, we explore the role of sociodemographic characteristics and proxies of pathologies as correlates of mortality-related decline.

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Descriptive Data

Table 1
Descriptive Statistics for the Cognitive Indicator (Digit Letter) Over Age and Time-to-Death

	Chronological age				Time-to-death			
	Age	*n*	Estimate	*SE*	Years before death	*n*	Estimate	*SE*
Between-person variance			53.42	7.93			5.49	0.61
Within-person variance			7.93	0.46			7.53	0.42
ICC			.87				.42	
			M	*SD*			*M*	*SD*
	70	5	51.05	7.80	16	2	51.46	8.69
	71	9	58.55	6.80	15	11	59.96	6.35
	72	15	58.26	7.14	14	14	55.04	9.26
	73	13	54.69	10.43	13	24	55.08	9.41
	74	27	56.12	7.85	12	27	57.63	7.95
	75	31	55.98	7.49	11	27	56.83	6.55
	76	32	56.56	8.24	10	41	57.29	6.85
	77	25	55.23	8.68	9	42	54.43	9.36
	78	38	54.65	8.32	8	50	53.32	8.84
	79	41	54.45	8.16	7	63	53.72	8.56
	80	46	52.61	9.26	6	72	51.20	10.65
	81	39	52.83	8.62	5	93	50.44	9.32
	82	45	53.54	9.34	4	114	48.22	9.44
	83	41	51.60	7.72	3	116	47.41	8.96
	84	40	52.92	8.90	2	129	45.98	10.52
	85	57	52.25	9.63	1	124	45.90	9.96
	86	45	48.42	8.67	0	40	44.92	10.29
	87	42	49.44	11.15				

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Statistical Modeling

$$function_{ti} = \beta_{0i} + \beta_{1i}(time_{ti}) + \beta_{2i}(time_{ti}^2) + e_{ti},$$

$$\beta_{0i} = \gamma_{00} + \gamma_{01}T1time_i + u_{0i},$$

$$\beta_{1i} = \gamma_{10} + \gamma_{11}T1time_i + u_{1i}, \text{ and}$$

$$\beta_{2i} = \gamma_{20}$$

$$\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{age of death}_i) + \gamma_{02}(\text{SES}_i) + \gamma_{03}(\text{gender}_i) + \gamma_{04}(\text{comorbidities}_i) + \gamma_{05}(\text{disability}_i) + \gamma_{06}(\text{suspected dementia}_i) + u_{0i},$$

$$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{age at death}_i) + \gamma_{12}(\text{SES}_i) + \gamma_{13}(\text{gender}_i) + \gamma_{14}(\text{comorbidities}_i) + \gamma_{15}(\text{disability}_i) + \gamma_{16}(\text{suspected dementia}_i) + u_{1i}. \quad (3)$$

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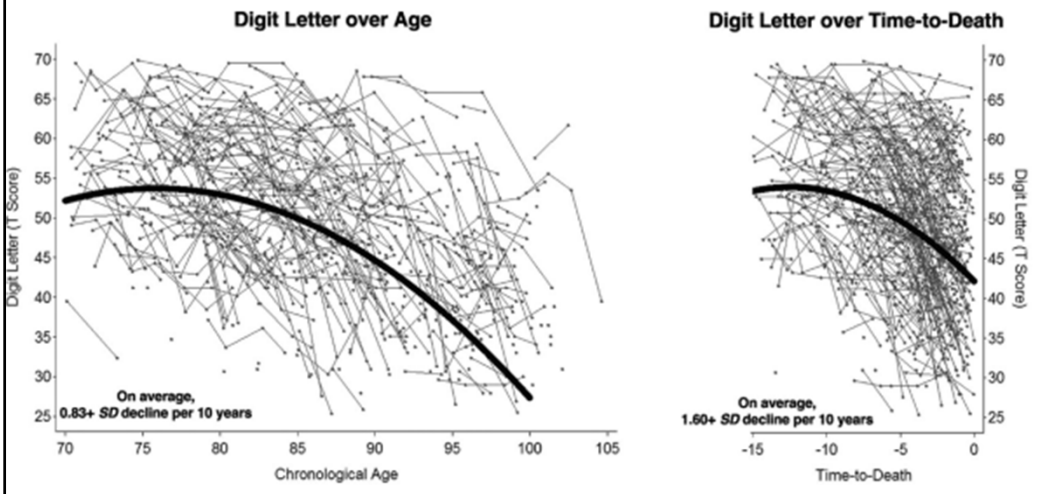
Observed and Expected Trajectories



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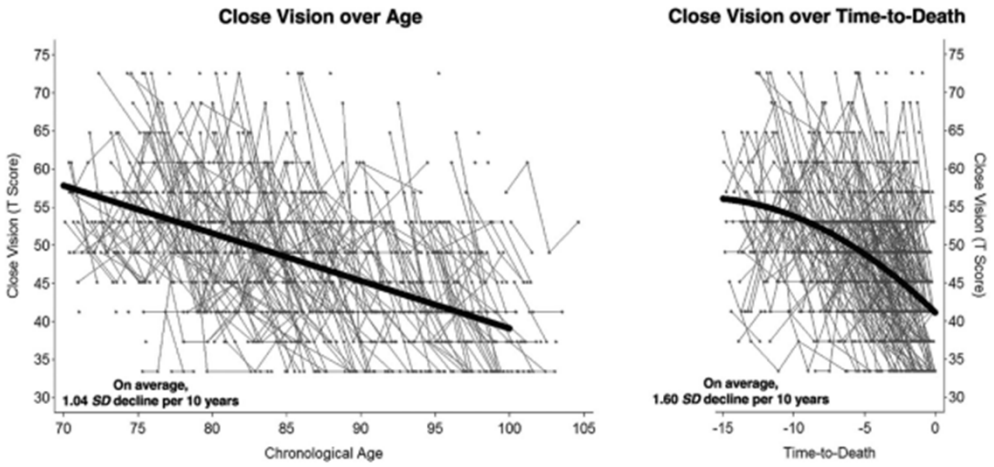
Observed and Expected Trajectories



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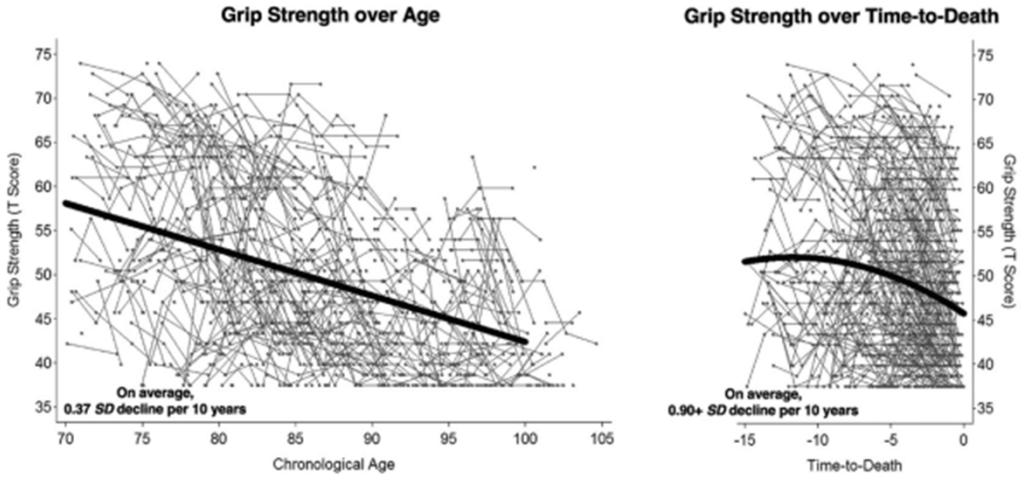
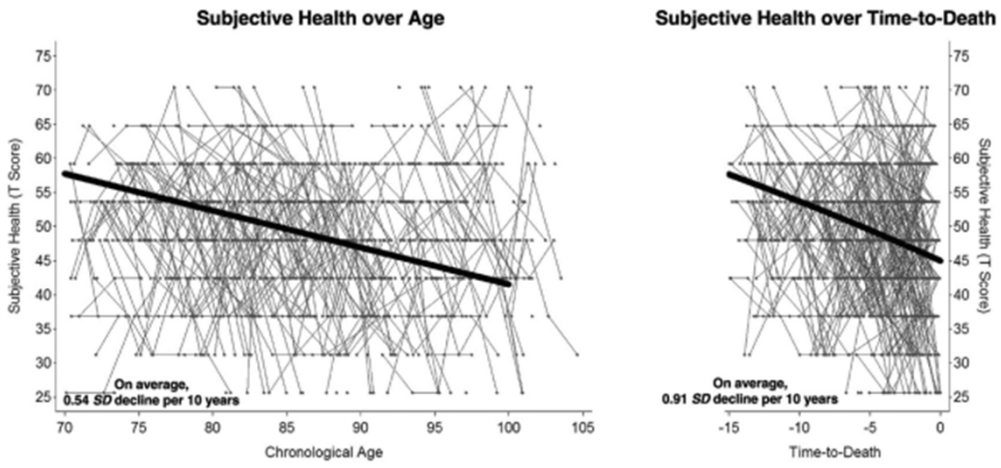
Observed and Expected Trajectories



41

Observed and Expected Trajectories

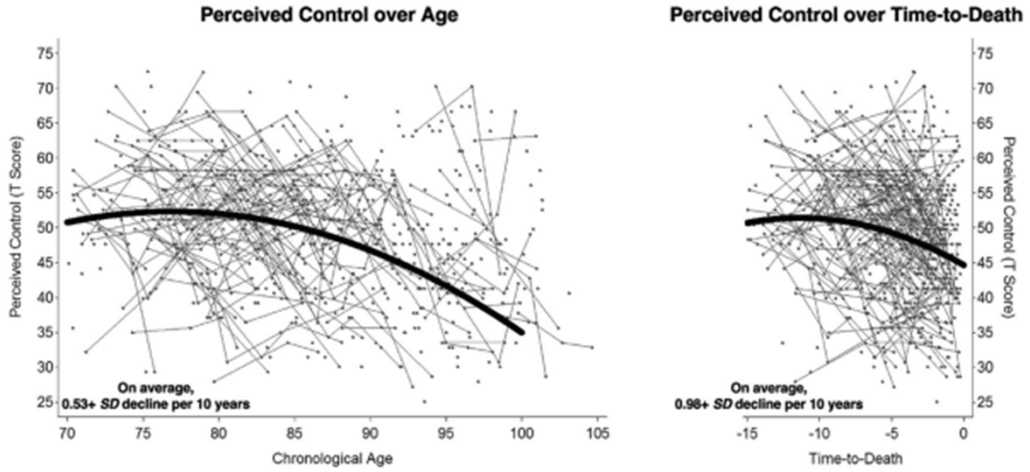


42

Observed and Expected Trajectories

43

Observed and Expected Trajectories



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Role of Covariates

Table 3
Growth Models for the Domain Indicators Over Time-to-Death: The Role of Between-Person Difference Factors

Variable	Cognitive: Digit Letter Estimate (*SE*)	Sensory: Close vision Estimate (*SE*)	Physical: Grip strength Estimate (*SE*)	Health: Self-rated health Estimate (*SE*)	Social: Loneliness Estimate (*SE*)	Self: Perceived control Estimate (*SE*)
Fixed effects						
Intercept, γ_{00}	46.13* (0.40)	44.95* (0.39)	48.08* (0.27)	47.43* (0.44)	51.66* (0.50)	47.50* (0.50)
Time-to-death, γ_{10}	−1.56* (0.11)	−1.46* (0.14)	−0.84* (0.10)	−0.86* (0.16)	0.46* (0.17)	−0.79* (0.18)
Time-to-death^2 γ_{20}	−0.07* (0.01)	−0.05* (0.02)	−0.03* (0.01)	−0.04* (0.02)	0.00 (0.01)	−0.03 (0.02)
Age at death, γ_{01}	−0.45* (0.06)	−0.34* (0.06)	−0.39* (0.04)	0.09 (0.06)	0.22* (0.07)	−0.20* (0.07)
SES, γ_{02}	0.25* (0.04)	0.09* (0.04)	0.07* (0.03)	0.08 (0.04)	−0.14* (0.05)	−0.02 (0.05)
Women, γ_{03}	0.49 (0.81)	−1.44 (0.78)	−9.72* (0.56)	−1.87* (0.90)	1.65* (0.99)	−2.74* (0.99)
Comorbidities, γ_{04}	−0.05 (0.04)	−0.05 (0.04)	−0.09* (0.03)	−0.09* (0.04)	0.11* (0.05)	0.01 (0.05)
Disability, γ_{05}	−2.98* (0.85)	−1.52 (0.82)	−1.66* (0.59)	−0.81 (0.95)	0.80 (1.05)	−4.46* (1.05)
Sus. dementia, γ_{06}	−6.68* (0.84)	−0.99 (0.81)	−0.85* (0.58)	1.23 (0.93)	0.67 (1.03)	1.31 (1.03)
Age at Death × Time-to-Death, γ_{11}	−0.03* (0.01)	−0.01 (0.01)	0.02* (0.01)	−0.01 (0.01)	0.00 (0.01)	−0.02 (0.01)
SES × Time-to-Death, γ_{12}	0.00 (0.01)	−0.02* (0.01)	0.00 (0.01)	−0.01 (0.01)	0.01 (0.01)	−0.01 (0.01)
Women × Time-to-Death, γ_{13}	−0.04 (0.14)	−0.01 (0.17)	0.49* (0.11)	0.19 (0.16)	−0.22 (0.16)	0.15 (0.17)
Comorbidities × Time-to-Death, γ_{14}	0.00 (0.01)	0.00 (0.01)	−0.01* (0.00)	0.01 (0.01)	−0.01 (0.01)	−0.01 (0.01)
Disability × Time-to-Death, γ_{15}	−0.32* (0.15)	−0.18 (0.19)	−0.29* (0.12)	0.07 (0.18)	0.24 (0.17)	−0.04 (0.18)
Sus. Dementia × Time-to-Death, γ_{16}	−0.59* (0.23)	0.26 (0.18)	0.04 (0.11)	0.37* (0.17)	0.01 (0.17)	0.57* (0.18)
Sus. Dementia × Time-to-Death^2, γ_{17}	−0.06* (0.02)	—	—	—	—	—
Random effects						
Intercept, σ^2_{u0}	47.33* (4.31)	36.69* (4.41)	17.19* (2.18)	45.84* (4.92)	63.40* (7.45)	59.38* (7.59)
Time-to-death, σ^2_{u1}	0.34* (0.11)	0.62* (0.15)	0.01 (0.00)	—[a]	0.07 (0.14)	0.03 (0.18)
Cov. Intercept × Time-to-Death, σ_{u0u1}	1.56* (0.54)	2.72* (0.69)	−0.37 (0.26)	—[a]	1.42 (0.98)	0.53 (1.00)
Explained variance (between person)						
In intercept, σ^2_{u0}	.48	.28	.72	.13	.15	.14
In time-to-death, σ^2_{u1}	.38	.26	.94	—[a]	—[a]	—[a]
Residual, σ^2_r	11.47* (0.83)	26.89* (1.80)	17.47* (0.97)	44.75* (2.51)	28.36* (2.87)	32.05* (3.53)

Note. *N*s range between 404 (Digit Letter) and 438 (perceived control) who provided between 739 (perceived control) and 1,076 observations (close vision). Unstandardized estimates and standard errors are presented. Intercept is located at 2 years prior to death. Level 2 versions of time-to-death were not included because many of these were previously found to be nonsignificant. SES = socioeconomic status; Sus. Dementia = Suspected dementia; Cov. intercept = Covariance intercept. Dashes indicate that effect was not estimated.
[a] For model convergence, variance of time-to-death and Covariance Intercept × Time-to-Death could not be estimated.
* $p < .05$.

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5. Latent Variable Models of Change

McArdle, J. J. (2009). Latent variable modeling of differences and changes with longitudinal data. *Annual Review of Psychology, 60*, 577-605.

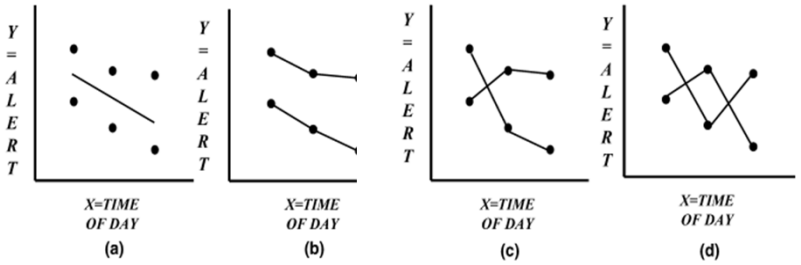

Figure 1

Alternative plots of cross-sectional and longitudinal data. (*a*) Cross-sectional measurements, (*b*) longitudinal measurements, (*c*) one longitudinal alternative, and (*d*) another longitudinal alternative.

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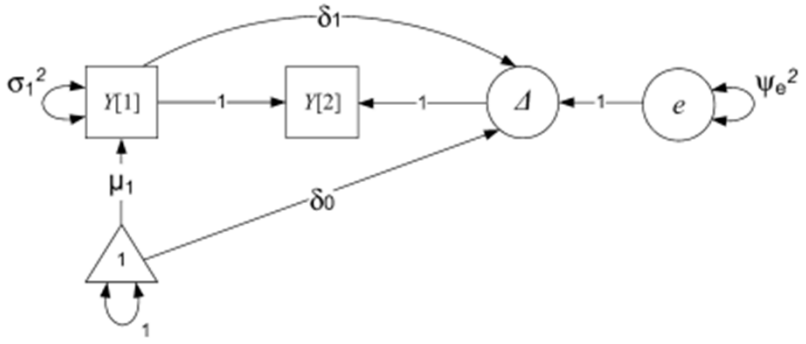
Univariate Latent Change Score Model



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Raz et al. (2008)

Raz, N., Lindenberger, U., Ghisletta, P., Rodrigue, K. M., Kennedy, K. M., & Acker, J. D. (2008). Neuroanatomical correlates of fluid intelligence in healthy adults and persons with vascular risk factors. Cerebral Cortex, 18, 718-726.

The main objective of this study was to examine the effects of regional brain changes on cognitive decline and the modifying influence of vascular risk (VR) factors. We present latent difference score analyses of associations among 5-year changes in 12 regional brain volumes and age-sensitive cognitive functions in 87 adults (32 with identifiable VR factors). We found reliable individual differences in volume change for 11 of the 12 brain regions but not in the cognitive measures that showed average longitudinal decline. Thus, associations between rates of change in fluid intelligence and brain volumes could not be assessed. We observed, however, that lower levels of fluid intelligence were associated with smaller prefrontal and hippocampal volumes. Lower fluid intelligence scores were also linked to greater longitudinal shrinkage of the entorhinal cortex (EC). After accounting for the effects of age, sex, and VR factors, the orbitofrontal cortex and the prefrontal white matter (PFw) volumes as well as the 5-year change in the EC volume predicted fluid intelligence level. VR was independently associated with smaller prefrontal volumes and lower fluid intelligence.

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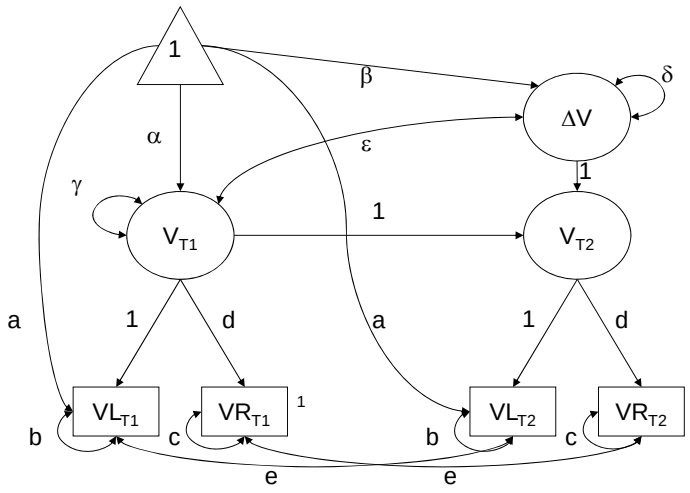
Multivariate Latent Change Score Model



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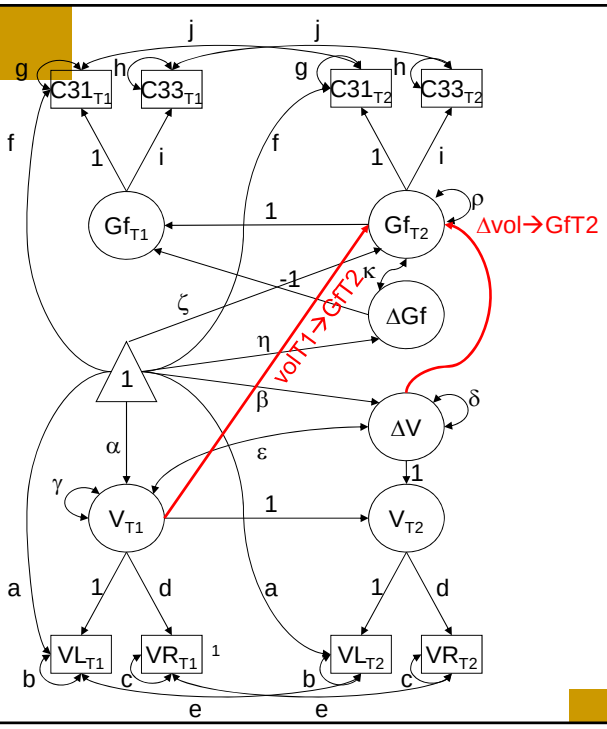

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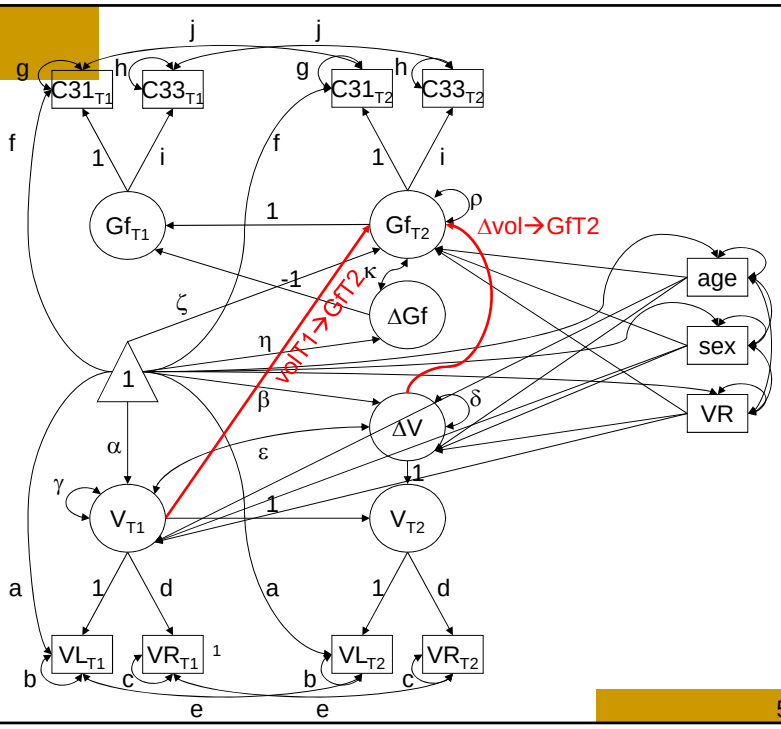

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General Results

Gf: average change, but no variance in change

Associations between volumes of LPFC, OFC, PFw, HE, EC and Gf

Volume change in HC and EC correlate with Gf

Greater age associated with

- **lower Gf performance**
- **smaller LPFC, OFC, PFw, HC volume**
- **Greater PFw and EC shrinkage**

No sex or cardio-vascular effects

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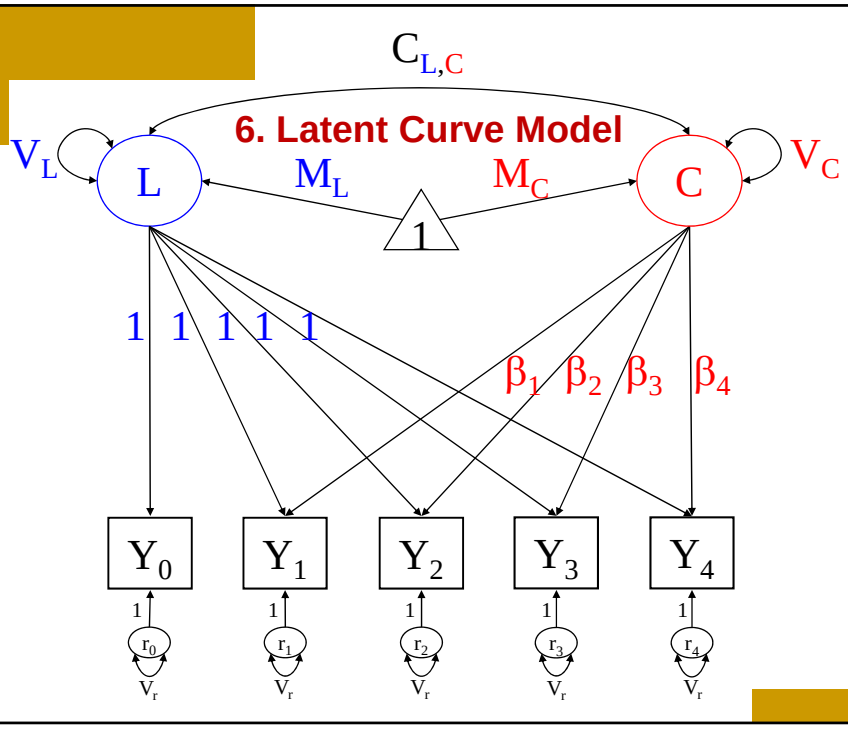
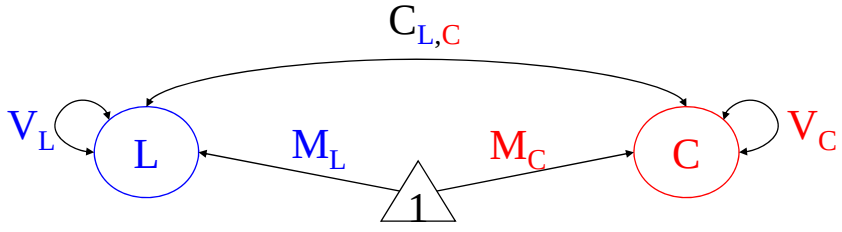
6. Latent Curve Model



Main Features of LCM



M_L, M_C: Mean of level, change
V_L, V_C: Variance of level, change
$C_{L,C}$: Covariance level-change
β_t: function of change
V_r: residual variance

Latent Curve Model / Linear Mixed Effects Model

Under several conditions, the two approaches are equivalent.

Generally speaking, the LCM approach is more flexible, allows more extensions, but also requires a greater understanding.

Computationally speaking, the LMEM approach is more efficient (especially with sparse data)

55

Singer et al. (2003)

Singer, T., Verhaeghen, P., Ghisletta, P., Lindenberger, U., & Baltes, P. B. (2003). The fate of cognition in very old age : Six-year longitudinal findings in the Berlin Aging Study (BASE). Psychology and Aging, 18, 318-331.

The authors report full-information longitudinal age gradients in 4 intellectual abilities on the basis of 6-year longitudinal changes in 132 individuals (mean age at T 1 = 78.27, age range = 70–100) from the Berlin Aging Study. Relative to the cross-sectional parent sample (N=516, mean age at T 1 = 84.92 years), this sample was positively selected because of differential mortality and experimental attrition. Perceptual speed, memory, and fluency declined with age. In contrast, knowledge remained stable up to age 90, with evidence for decline thereafter. Age gradients were more negative in old old (n = 66, mean age at T 1 = 83.04) than in old (n = 66, mean age at T 1 = 73.77) participants. Rates of decline did not differ reliably between men and women or between participants with high versus low life-history status. They conclude that intellectual development after age 70 varies by distance to death, age, and intellectual ability domain.

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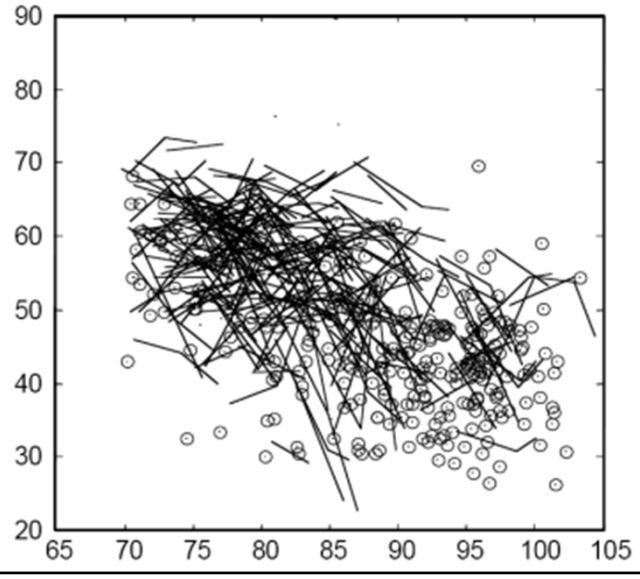
Sample Data



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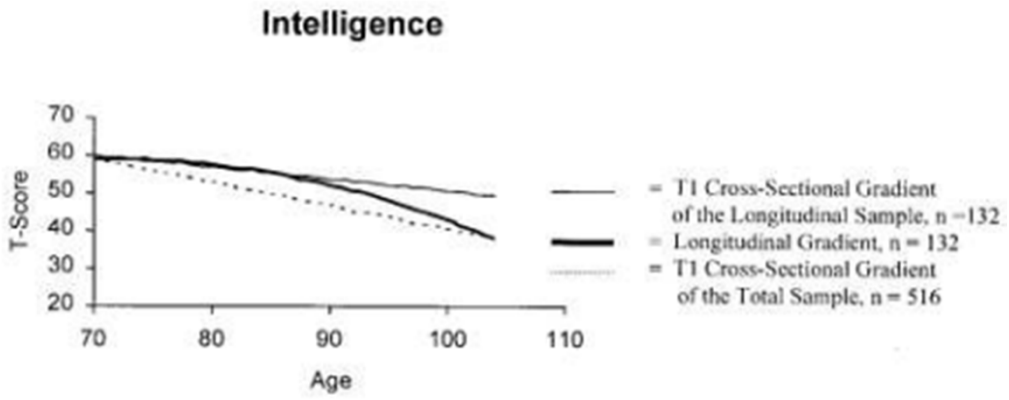
Results: Expected Trajectories



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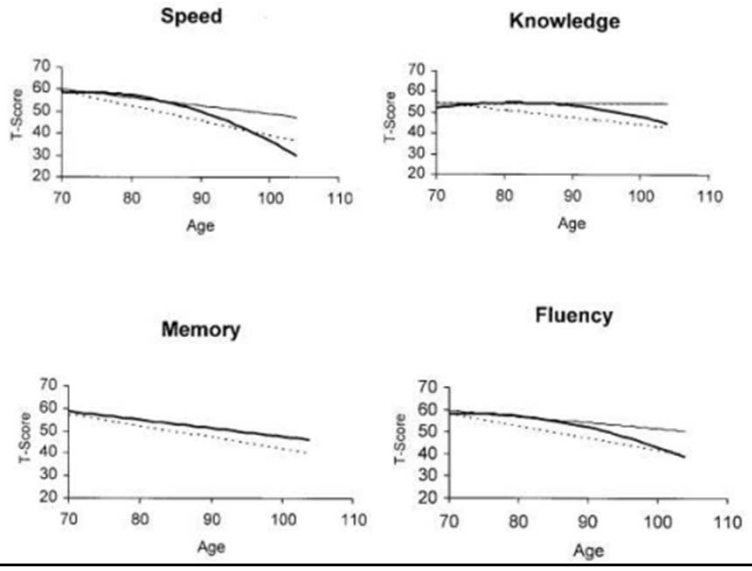
Results : Expected Trajectories



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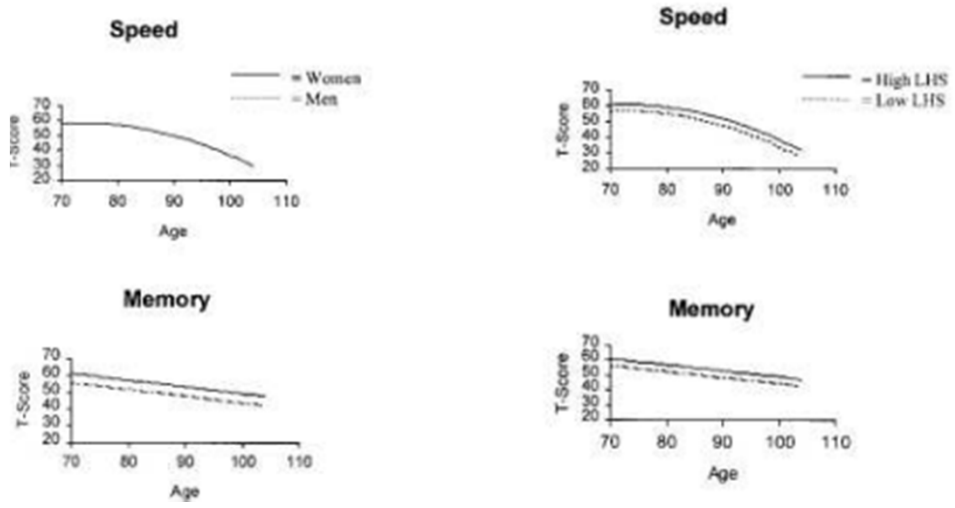
Results : Sex and Life-History Effects



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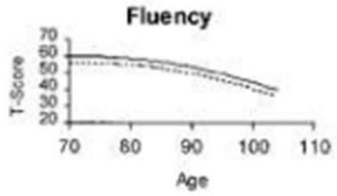
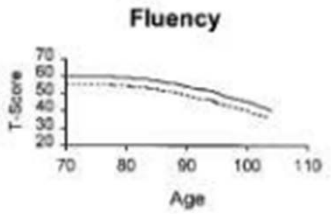
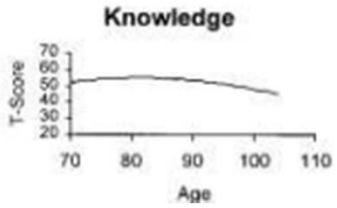
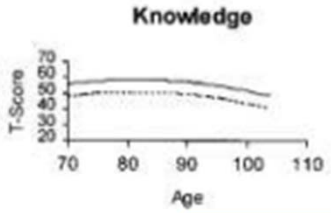
Results : Sex and Life-History Effects









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Multivariate Latent Curve Model

Rather than analyzing change in only one variable, consider multiple variables.

Allows investigating interrelationships in change.

For each variable, apply the LCM and estimate properties of each variable's level and change component.

Consider correlations among the various levels and changes.

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Stoolmiller (1994)

Stoolmiller, M. (1994). Antisocial behavior, delinquent peer association, and unsupervised wandering for boys : Growth and change from childhood to early adolescence. *Multivariate Behavioral Research, 29*, 263-288.

Latent growth curve analysis was used to study individual differences in initial status and growth rates of antisocial behavior, delinquent peer association, and unsupervised wandering during the transition from childhood to early adolescence for a sample of 206, primarily working-class, European-American boys. All three constructs showed significant individual differences in initial status at Grade 4 and growth rates from Grade 4 to Grade 8. Wandering and delinquent peer association showed positive mean trends. Linear growth curves adequately described growth for delinquent peer association and antisocial behavior. Growth on wandering was linear up to Grade 7 and then showed positive acceleration from Grade 7 to Grade 8. All three constructs were highly related at the initial assessment point. Individual differences in growth rates were highly correlated on all three constructs. The findings were discussed in terms of the trait-confluence model for peer influence on antisocial behavior.

Descriptive Statistics of the Data

Table 1
Univariate Descriptives Statistics for Constructs

	Construct											
	Delinquent Peers				Antisocial				Wandering			
	Grade				Grade				Grade			
	4	6	7	8	4	6	7	8	4	6	7	8
Mean	.33	.37	.40	.42	.37	.40	.40	.39	.29	.35	.40	.50
Variance	.11	.13	.14	.16	.06	.07	.07	.07	.04	.07	.07	.11
Skewness	1.23	.89	.87	.82	.81	.74	.90	.94	.76	.92	.94	1.01
Kurtosis	1.00	.02	-.05	-.45	.35	.22	.62	.57	.96	.63	1.30	.82
N	204	203	203	202	203	200	203	201	204	203	202	203

Descriptive Statistics of the Data

Table 2
Bivariate Correlations for Constructs

	Construct											
	Delinquent Peers				Antisocial				Wandering			
	Grade				Grade				Grade			
	4	6	7	8	4	6	7	8	4	6	7	8
Delinquent	1.00											
Peers	.49	1.00										
	.50	.60	1.00									
	.46	.61	.68	1.00								
Antisocial	.59	.52	.47	.45	1.00							
	.45	.64	.55	.58	.64	1.00						
	.47	.58	.65	.60	.64	.75	1.00					
	.42	.50	.54	.64	.59	.69	.75	1.00				
Wandering	.40	.36	.26	.26	.46	.41	.32	.27	1.00			
	.34	.44	.37	.40	.43	.54	.45	.44	.41	1.00		
	.34	.40	.45	.45	.43	.44	.45	.38	.37	.52	1.00	
	.28	.34	.44	.40	.36	.40	.43	.41	.31	.51	.54	1.00

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Results: Interrelationships of levels and changes

Table 4
Multivariate Growth Model of Antisocial, Delinquent Peers and Wandering

Correlations Among Components of Growth						
Delinquent Peers intercept	1.00					
Antisocial intercept	.84	1.00				
Wandering intercept	.78	.83	1.00			
Delinquent Peers slope	.00	.09	-.18	1.00		
Antisocial slope	-.09	.00	-.36	.73	1.00	
Wandering slope/shape	.08	.14	.00	.63	.55	1.00

Time-Specific Correlations	
Antisocial 4th, Delinquent Peers 4th	.24
Antisocial 6th, Delinquent Peers 6th	.27
Antisocial 7th, Delinquent Peers 7th	.28
Antisocial 8th, Delinquent Peers 8th	.22

$\chi 2(58) = 44.22$ $p = .909$ *BBN* = .969 *CFI* = 1.000

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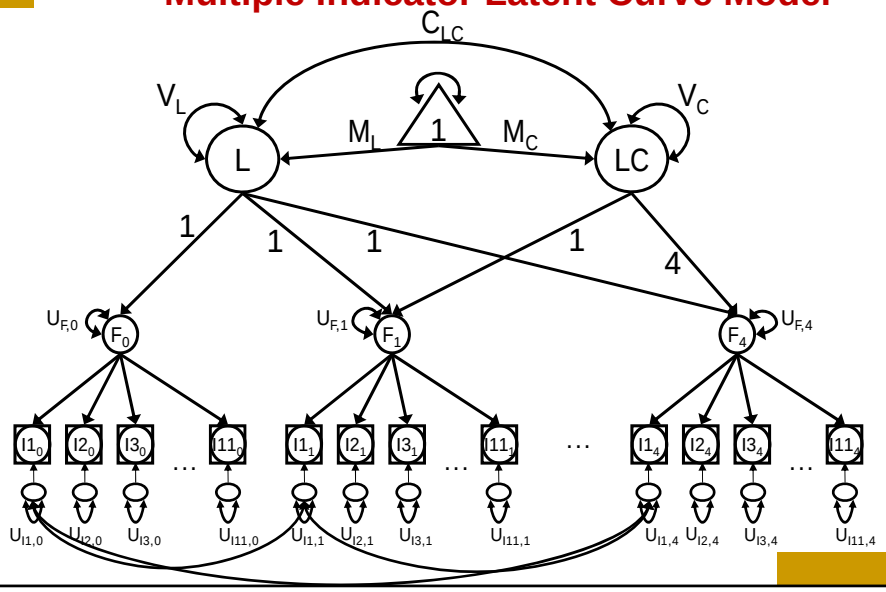
Multiple Indicator Latent Curve Model



7. Nonlinear Mixed Effects Model

Why implement nonlinear functions of change?

1. **Limitations of polynomials**
2. **Difficult interpretation of transformed outcomes**
3. **Several outcomes follow nonlinear functions of change**

Nonlinear Mixed Effects Model

The NLMM can be defined as (Davidian & Giltinan, 1995)

$$\boldsymbol{y}_i = \boldsymbol{f}_i(\beta_i) + \boldsymbol{e}_i$$

$$\beta_i = \boldsymbol{d}(\boldsymbol{a}_i, \beta, \boldsymbol{b}_i)$$

- $\boldsymbol{y}_i$ is the $(n_i \times 1)$ data vector for the ith individual $(N = \sum_{i=1}^{m} n_i)$
- $\boldsymbol{f}_i = [f(x_{i1}, \beta_i), \ldots, f(x_{in_i}, \beta_i)]'$
- $\boldsymbol{x}_i$ is the vector of predictors
- $\boldsymbol{e}_i$ is vector of random errors
- $\boldsymbol{d}$ is a function of $\boldsymbol{a}_i$, β, and $\boldsymbol{b}_i$
- $\boldsymbol{a}_i$ is a vector of individual characteristics
- β is a vector of fixed effects
- $\boldsymbol{b}_i$ is a vector of random effects

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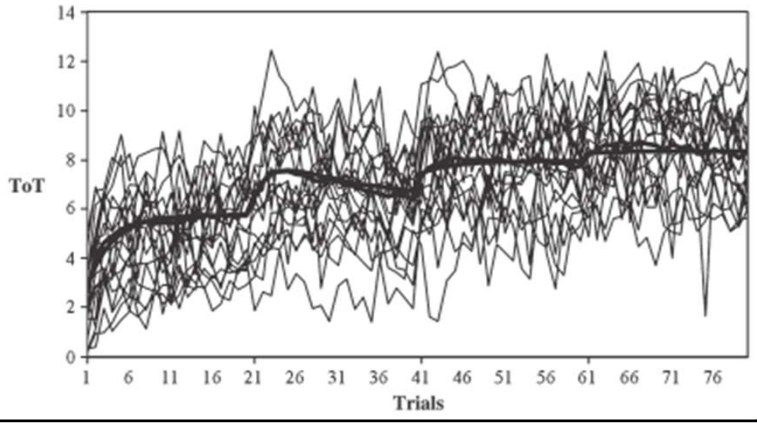
Ghisletta et al. (2010)

Ghisletta, P., Kennedy, K. M., Rodrigue, K. M., Lindenberger, U., & Raz, N. (2010). Adult age differences and the role of cognitive resources in perceptual-motor skill acquisition: Application of a multilevel negative exponential model. *Journal of Gerontology: Psychological Sciences, 65*, 163–173.



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Nonlinear Change Function

$$Y_{t,i} = \beta_i - (\beta_i - \alpha_i) \cdot \left(e^{-\gamma_i (t_{t,i} - 1)} - e^{-\delta_i (t_{t,i} - 1)} \right) + r_{t,i}$$

- **α: initial performance**
- **β: asymptotic performance**
- **γ: rate of improvement**
- **δ: rate of decline**

Results

Table 1. Parameter Estimates and Standard Errors of Analysis Without Statistical Control for Age and Cognitive Resources

	Fixed effects				Random effects			
Block	α	γ	δ	β	α	γ	δ	β
1	2.855 (0.225)	0.336 (0.029)	—	5.759 (0.230)	2.863 (0.489)	0.070 (0.019)	—	3.806 (0.551)
2	4.430 (0.489)	0.525 (0.137)	0.100 (0.025)	6.461 (0.248)	*10.222 (9.903)*	*0.031 (0.454)*	*0.034 (0.038)*	3.638 (0.846)
3	7.448 (0.258)	0.297 (0.046)	—	7.946 (0.242)	4.169 (0.679)	*1.269 (0.816)*	—	4.125 (0.602)
4	8.282 (0.233)	0.228 (0.042)	—	8.362 (0.233)	3.473 (0.574)	*48.065 (162.757)*	—	3.992 (0.612)

Notes: The fit indices of this model were $\chi^2(df = 3,136, N = 102) = 5,630.108$, RMSEA = .088 (90% CI = [.085–.092]), SRMR = .038, and CFI = .828. Parameters are presented with point estimates and, in parentheses, standard errors. α (initial performance), γ (acquisition rate), δ (decline rate), and β (final performance) are the parameters of the negative exponential function. Italicized numbers refer to statistically nonsignificant parameter estimates. RMSEA = root mean square error of approximation; CI = confidence interval; SRMR = standardized root mean square residual; CFI = comparative fit index.

Results

Table 4. Correlations Among Learning Parameters in Analyses Without or With Predictors in Lower or Upper Diagonal, Respectively

	Block 1			Block 2				Block 3			Block 4		
	α_1	γ_1	β_1	α_2	γ_2	δ_2	β_2	α_3	γ_3	β_3	α_4	γ_4	β_4
α_1	—	−.196	.747[a]	.475	.082	.030	.839[a]	.646[a]	−.041	.642[a]	.651[a]	−.122	.619[a]
γ_1	−.119	—	−.306[a]	−.670[b]	.721[b]	.808	−.169	−.166	−.153	−.169	−.172	.353[b]	−.135
β_1	.801[a]	−.247[a]	—	.457	−.032	−.122	.980[a]	.837[a]	−.083	.830[a]	.793[a]	−.130	.700[a]
α_2	.576	−.555	.566[b]	—	.186	−.881	.517	.391	−.375	.394	.343	−.159	.217
γ_2	.393	−2.361	.084	1.419	—	.227	.318	−.147	−.120	.065	−.062	−.102	−.134
δ_2	.069	.691[b]	−.049	−.714	−1.273	—	−.221	.141	.356	−.029	.185	.247	.133
β_2	.834[a]	−.074	.939[a]	.502	.026	.101	—	1.028[a]	−.128	.943[a]	1.009[a]	−.078	.875[a]
α_3	.707[a]	−.129	.870[a]	.541	−.333	.135	.991[a]	—	−.045	.866[a]	.959[a]	−.119	.782[a]
γ_3	.039	.170	−.024	−.324	−.125	.295	−.066	−.016	—	−.122	.027	.567[b]	−.003
β_3	.711[a]	−.141	.867[a]	.513[b]	.192	.026	.926[a]	.903[a]	−.090	—	.892[a]	−.125	.877[a]
α_4	.706[a]	−.173	.825[a]	.511	.299	.075	.918[a]	.945[a]	.019	.902[a]	—	−.019	.882[a]
γ_4	−.060	.388[b]	−.092	−.145	−.569	.288	−.010	−.092	.570[b]	−.114	−.094	—	−.269
β_4	.685[a]	−.132	.769[a]	.394	−.167	.095	.864[a]	.844[a]	−.016	.909[a]	.912[a]	−.267	—

Notes: α (initial performance), γ (acquisition rate), δ (decline rate), and β (final performance) are the parameters of the negative exponential function. Indices refer to the block.

[a] Statistically significant correlations at the $p = .01$ level.

[b] Correlations that resulted statistically significant but that must be ignored because they are not defined (given that at least one of the two variables being correlated had no variance.

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Results

Table 3. Regression Weights (and *SE*s) of the Cognitive Resource Variables and Age in the Prediction of the Learning Components in Each Block

	LS	CS	SJS	SR	WCST	Age
α_1	0.004 (0.018)	0.008 (0.014)	0.165 (0.123)	0.142[a] (0.060)	0.006 (0.010)	−0.006 (0.012)
γ_1	0.003 (0.004)	0.000 (0.003)	0.000 (0.024)	0.007 (0.010)	−0.002 (0.002)	0.006[a] (0.003)
β_1	−0.004 (0.002)	0.002 (0.014)	0.157 (0.129)	0.157[a] (0.057)	0.000 (0.010)	−0.024 (0.013)
α_2	−0.089 (0.146)	0.088 (0.126)	0.007 (0.469)	0.005 (0.235)	−0.002 (0.061)	−0.065 (0.107)
γ_2	−0.029 (0.017)	0.028 (0.013)[b]	−0.017 (0.110)	−0.010 (0.047)	0.013 (0.009)	−0.018 (0.012)
δ_2	0.007 (0.006)	−0.006 (0.004)	0.006 (0.029)	0.012 (0.013)	−0.003 (0.003)	0.005 (0.005)
β_2	0.023 (0.021)	−0.023 (0.015)	0.158 (0.144)	0.167[a] (0.063)	−0.016 (0.012)	−0.013 (0.014)
α_3	0.014 (0.020)	−0.011 (0.015)	0.125 (0.138)	0.149[a] (0.059)	−0.010 (0.011)	−0.034[a] (0.014)
γ_3	−0.008 (0.017)	0.003 (0.012)	−0.019 (0.113)	0.073 (0.052)	0.006 (0.009)	0.002 (0.011)
β_3	0.008 (0.020)	−0.005 (0.014)	0.204 (0.133)	0.116[a] (0.058)	−0.006 (0.011)	−0.028[a] (0.013)
α_4	0.020 (0.018)	0.004 (0.014)	0.175 (0.122)	0.080 (0.055)	0.010 (0.010)	−0.042[a] (0.012)
γ_4	−0.037 (0.084)	−0.025 (0.060)	−0.194 (0.529)	0.392 (0.514)	−0.029 (0.056)	0.053 (0.080)
β_4	0.009 (0.019)	−0.001 (0.014)	0.280[a] (0.127)	0.074 (0.057)	−0.002 (0.010)	−0.033[a] (0.013)

Notes: α (initial performance), γ (acquisition rate), δ (decline rate), and β (final performance) are the parameters of the negative exponential function. Indices refer to the block. LS = Listening Span; CS = Computation Span; SJS = Size Judgment Span; SR = Spatial Relation of Woodcock–Johnson Psycho-Educational Battery–Revised; WCST = Wisconsin Card Sorting Task.

[a] Statistically significant parameters at the $p = .01$ level.

[b] An effect that resulted statistically significant but that must be ignored because it is not defined (given that in the previous model the dependent variable of this effect had no variance).

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8. Conclusions

- **Lifespan developmental psychology has come a long way**
- **Many theoretical concepts of lifespan psychology have been operationalized with advanced methodologies and statistical models**
- **Many theoretical, methodological, and statistical advances have taken place, mutually feeding each other**
- **Nevertheless, lifespan developmental psychology has still a long way to go!!**
- **There is no need to be a sect! Any developmental field can become lifespan – actually, any field of research in psychology!**
- **Go for it!**

Cognitive development across the lifespan: Conceptual, methodological and analytical challenges of a lifespan approach

Part 1

Paolo Ghisletta
University of Geneva
ISSBD Workshop, Sept 3-5 2015