

Considerations in Selecting Amongst Alternative Metrics of Time

Lesa Hoffman, PhD

Originally presented 3/27/13 at the 9th International
Multilevel Conference at Utrecht University, the Netherlands

Goals of Longitudinal* Modeling

- 5 rationales of longitudinal research
 - Baltes & Nesselroade, 1979
 - Chapter 1: *Longitudinal Research in the Study of Behavior and Development*
- 7 levels of longitudinal analysis
 - Hofer & Sliwinski, 2006
 - Chapter 2: *Handbook of the Psychology of Aging (6th edition)*
- 7+ steps in longitudinal modeling
 - Singer & Willett, 2003
 - Chapter 4: *Applied Longitudinal Data Analysis*

*Applicable to both the MLM and SEM analytic frameworks

Steps in Longitudinal Analysis

1. Decompose **BP and WP variation**—Intraclass Correlation
 - **ICC** = proportion of outcome variance that is *constant* over time, and that results from *cross-sectional* differences

3. Describe pattern of *average change* over time (**fixed effects**) and *individual differences* therein (**random effects**)
 - Piecewise slopes models—Phases of discontinuous change
 - Polynomial models—Approximate nonlinear continuous change
 - Truly nonlinear models—Exponential or logistic change
 - Latent basis models—Estimate shape of nonlinear change

Steps in Longitudinal Analysis

4. Predict **inter-individual differences** in change
 - *Why do people need their own intercepts and slopes?*
5. Predict **intra-individual variation** from predicted change
 - *Why are you off your line today (time-specific influences)?*
6. Examine **multivariate relationships** → *regression paths*
 - *Between-person correlations among intercepts and slopes*
 - *Within-person covariation of residuals (or lead-lag associations)*
7. Examine other sources of underlying **heterogeneity**
 - *Mixture models for discrete types of individual differences*
 - *Predict individual differences in within-person variability*

Road Map

- Steps in longitudinal analysis
- **The missing step #2**
- Example: Alternative metrics of “time”
- What about just time?
- What else contributes to “time”?

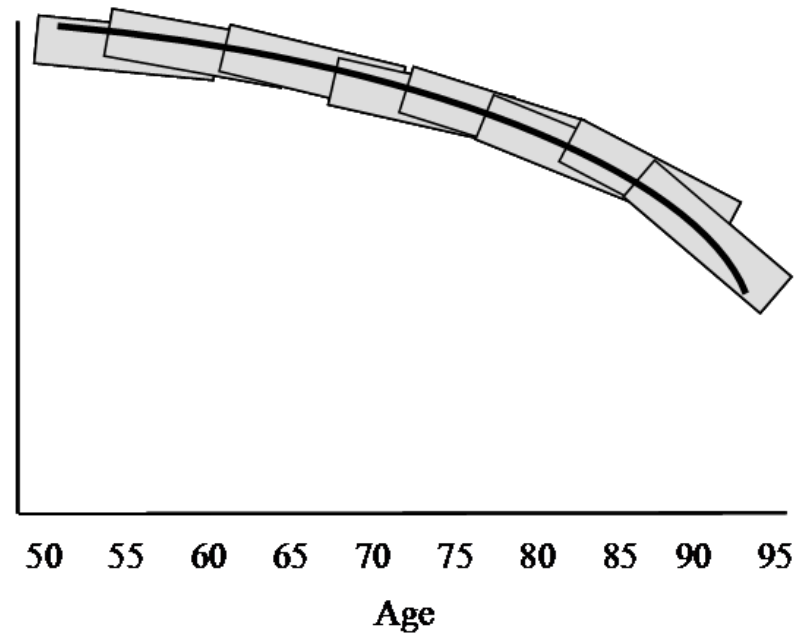
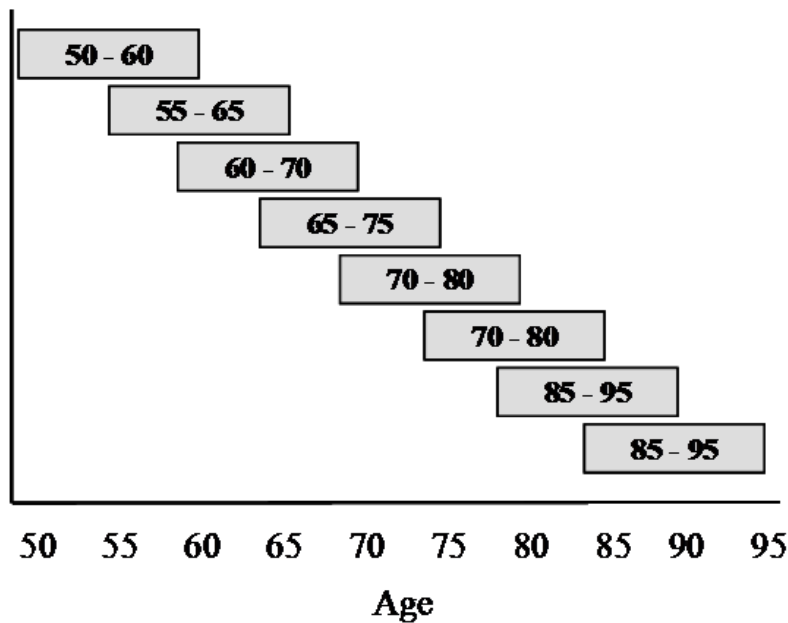
The Missing Step 2

- **Summary across steps:** The goal of creating statistical models of change is to describe the overall pattern of and predict individual differences in **change over time**.
- These models employ an often unrecognized assumption **that we know exactly what “time” should be**.
- So the missing Step 2 is a pre-cursor to every other step in longitudinal analysis, and involves 2 related concerns:
 - **What should “time” be?**
 - **How should “time” be modeled when people differ in “time”?**
 - Concerns apply specifically to *accelerated longitudinal designs*

Accelerated Longitudinal Designs

Want to do a longitudinal study but just don't have the time?

Accelerate: Model trajectories over a wider span of time than would be possible using only the observed longitudinal info...



The Missing Step 2

- **First: What should “time” be?**
 - Which **metric of time** best matches the **causal process** thought to be responsible for observed change?
 - Do **alternative metrics of time** for **multiple processes** create different pictures of change and individual differences therein?
 - Relevant for aligning different persons onto same time trajectory, but this distinction is **not relevant within persons**
- **Second: What do we do when people differ in “time”?**
 - **How should “time” be modeled in accelerated designs?**
 - When people begin a study at different points in time, how should we distinguish effects of **between-person differences** in time from effects of **within-person changes** in time?

Road Map

- Steps in longitudinal analysis
- The missing step #2
- **Example: Alternative metrics of “time”**
- What about just time?
- What else contributes to “time”?

Example Data:

Octogenarian (Twin) Study of Aging

- **173 persons (65% women)**

- Measured up to **5 occasions** over 8 years
- **Known** dates of birth and death
- **Estimated** dates of dementia diagnosis (91 Alz., 50 Vas., 32 Mixed)

- **Baseline occasion “time” variability:**

- 79 to 100 years of age ($M = 84$, $SD = 3$)
- -16 to 0 years from death ($M = -6$, $SD = 4$)
- -12 to 18 years from diagnosis ($M = 0$, $SD = 5$)

Correlation	Age	Death
Death	.23	
Dementia	.17	.52

- **Cognition outcomes (each T-scored):**

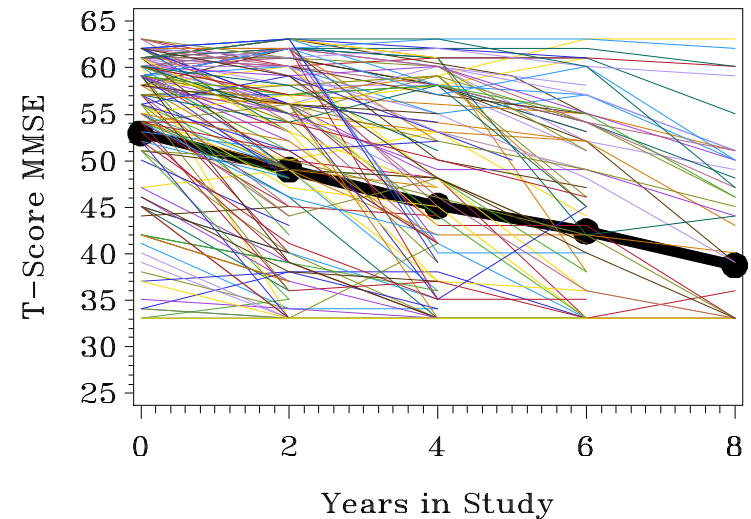
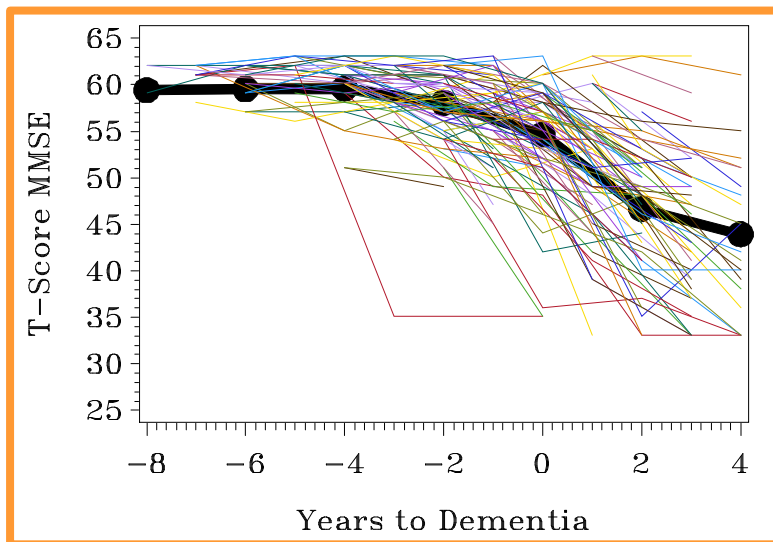
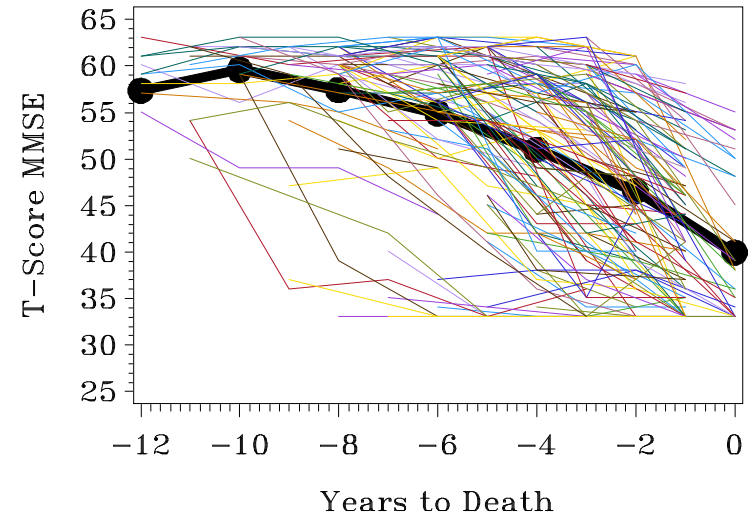
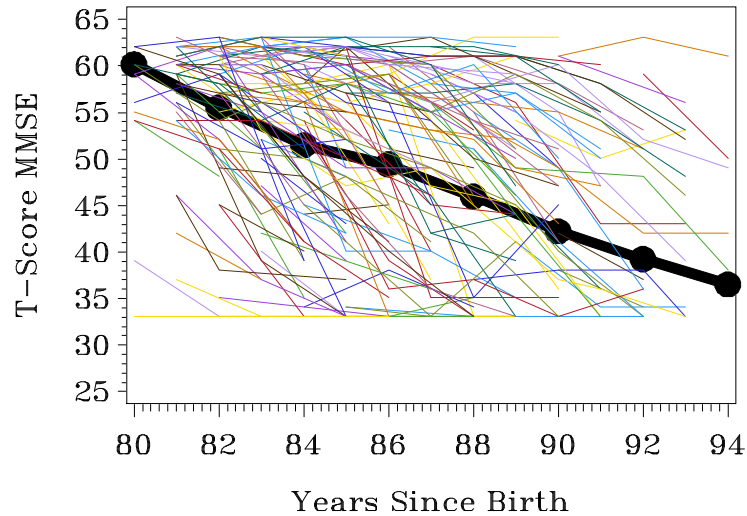
- General: Mini-Mental Status Exam
- Memory: Object Recall
- Spatial Reasoning: Block Design

#Persons per #Occasions				
1	2	3	4	5
28	37	36	36	35
29	31	39	29	18
37	32	31	22	19

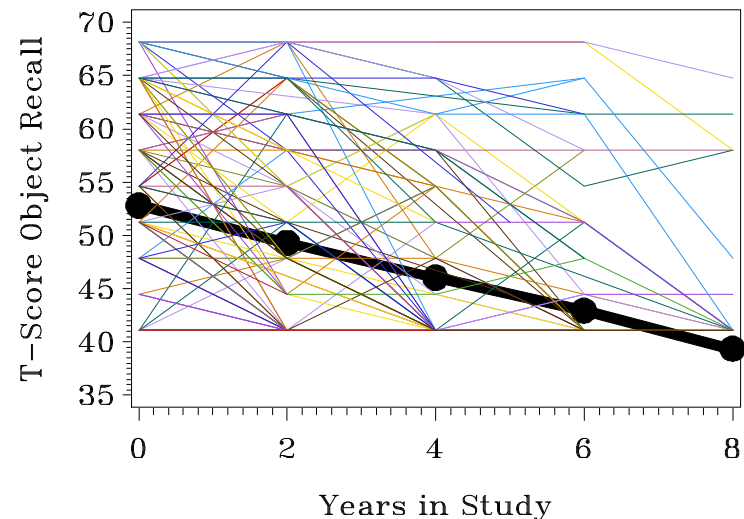
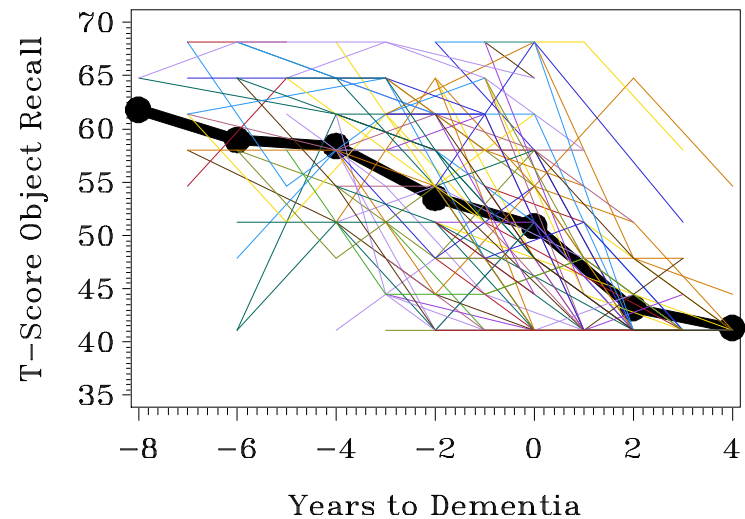
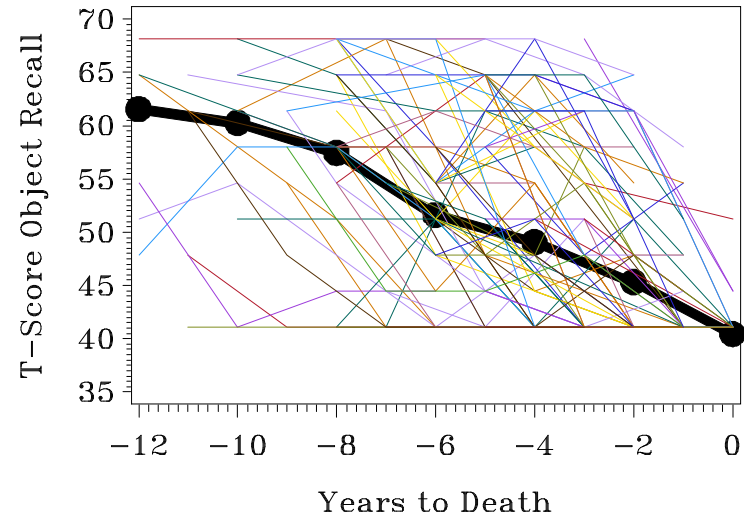
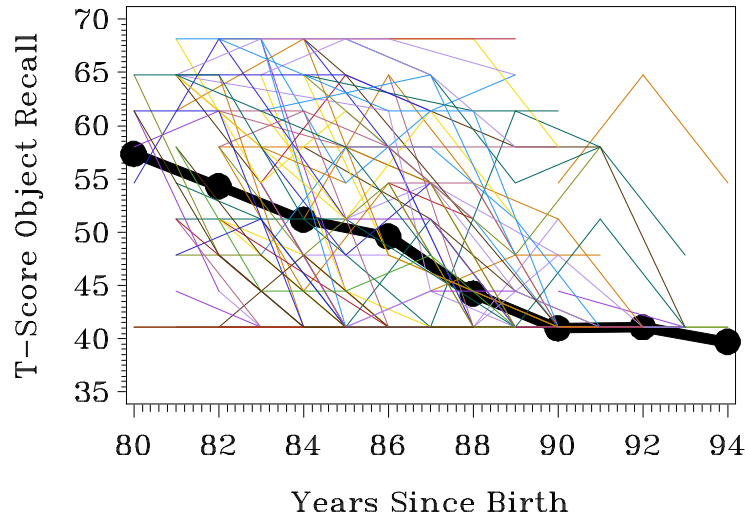
Alternative Metrics of Time (and ICC)

- Chronological Age as Time (47% BP)
 - Individual differences are organized around the mean level for a given **distance from birth** (84 years) and change with distance from birth
- Years to Death as Time (24% BP)
 - Individual differences are organized around the mean level for a given **distance from death** (−7 years) and change with distance from death
- Years to Dementia Diagnosis as Time (70% BP)
 - Individual differences are organized around the mean level for a given **distance from diagnosis** (=0) and change with distance from diagnosis
- Years in Study as Time (0% BP)
 - Individual differences are organized around the mean level for a given **distance from baseline** (=0) and change with distance from baseline

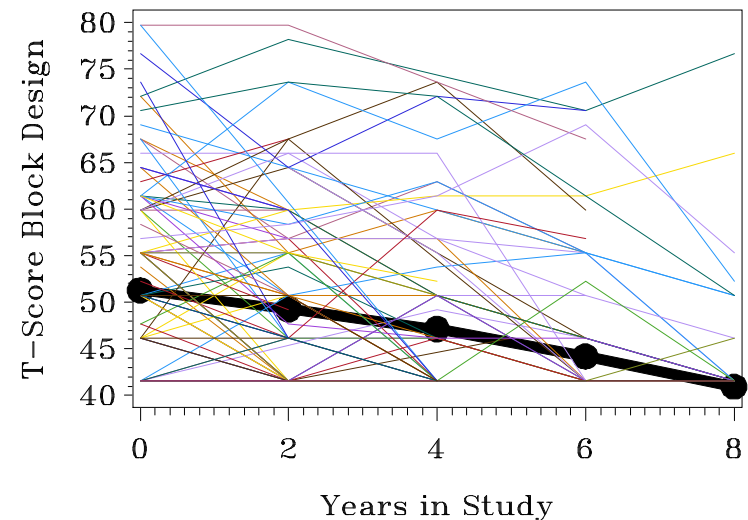
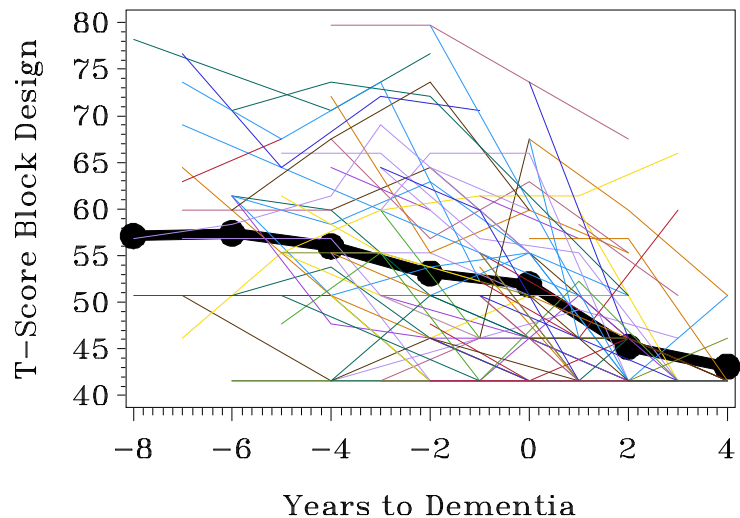
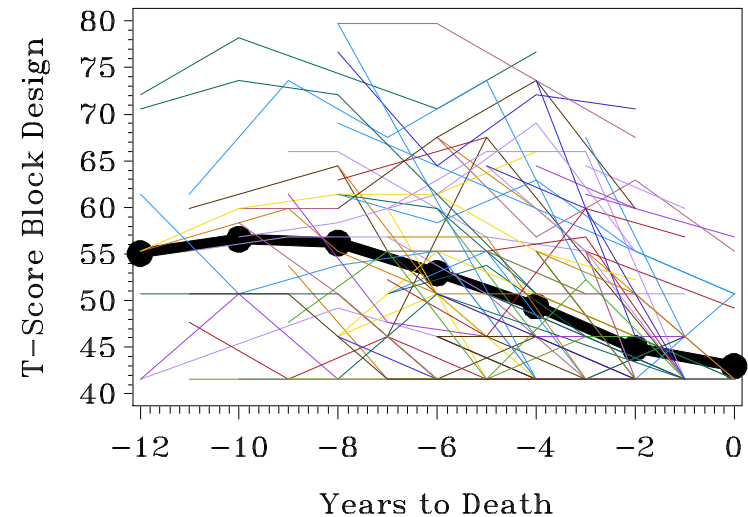
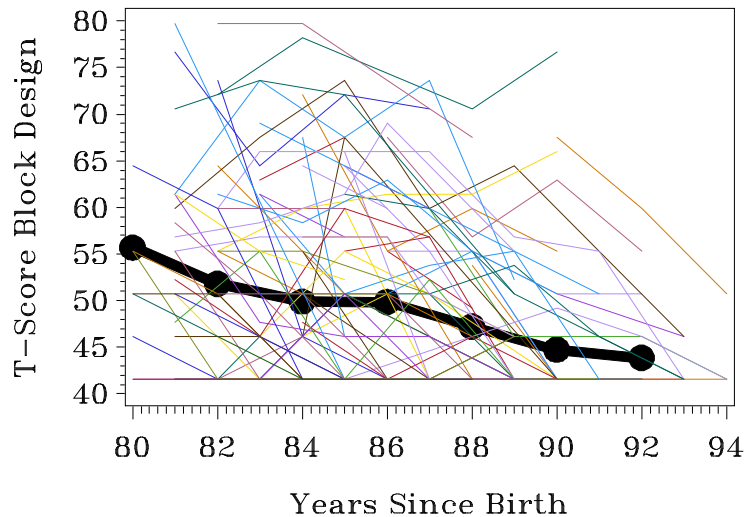
General Cognition: MMSE



Memory: Object Recall



Spatial Reasoning: Block Design



First Option: Age-as-Time

Level-1: $y_{ti} = \beta_{0i} + \beta_{1i}(\text{Age}_{ti}-84) + \beta_{2i}(\text{Age}_{ti}-84)^2 + e_{ti}$

Level-2 Equations → **Fixed** and **Random** Effects:

$\beta_{0i} =$
↑
Intercept
for person i

γ_{00}
↑
Fixed Intercept
(mean)

u_{0i}
↑
Random Intercept
Deviation

→ predicted Y when age=84

$\beta_{1i} =$
↑
Linear Slope
for person i

γ_{10}
↑
Fixed Linear Slope
(mean)

u_{1i}
↑
Random Linear Slope
Deviation

→ rate of Δ when age=84

$\beta_{2i} =$
↑
Quad Slope
for person i

γ_{20}
↑
Fixed Quad Slope
(mean)

u_{2i}
↑
Random Quad Slope
Deviation

→ $\frac{1}{2}$ rate of Δ in Δ per year

First Option: Age-as-Time

- If people differ in initial age, measuring change as a function of age requires assuming **age convergence**:
 - Younger people and older people differ *only* by age
 - Effects of between-person, **cross-sectional age differences** are equivalent to effects of within-person, **longitudinal age changes**
- Age convergence is not likely to hold when:
 - Initial **age range** is large (47% of age is BP here)
 - **Cohort** differences and **selection** effects are large
- Is exactly the same problem as not fully separating the BP and WP effects of **ANY** time-varying predictor
 - i.e., *conflated, convergence, composite, or smushed effect*

Examining Age Convergence Effects

Can use a variant of **grand-mean-centering** to test equivalence of BP and WP age effects empirically

Level-1 **Age-Based** Change:

$$y_{ti} = \beta_{0i} + \beta_{1i}(\text{Age}_{ti} - 84) + \beta_{2i}(\text{Age}_{ti} - 84)^2 + e_{ti}$$

Level-2 Equations:

$$\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{AgeT1}_i - 84) + U_{0i}$$

$$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{AgeT1}_i - 84) + U_{1i}$$

$$\beta_{2i} = \gamma_{20} + \gamma_{21}(\text{AgeT1}_i - 84) + U_{2i}$$

Cross-level interactions. → Systematically-varying effects.

AgeT1 → Incremental effect of cross-sectional age (**cohort**)

Use **age at time 1** (or birth year) instead of mean age to lessen bias from attrition-related missing data

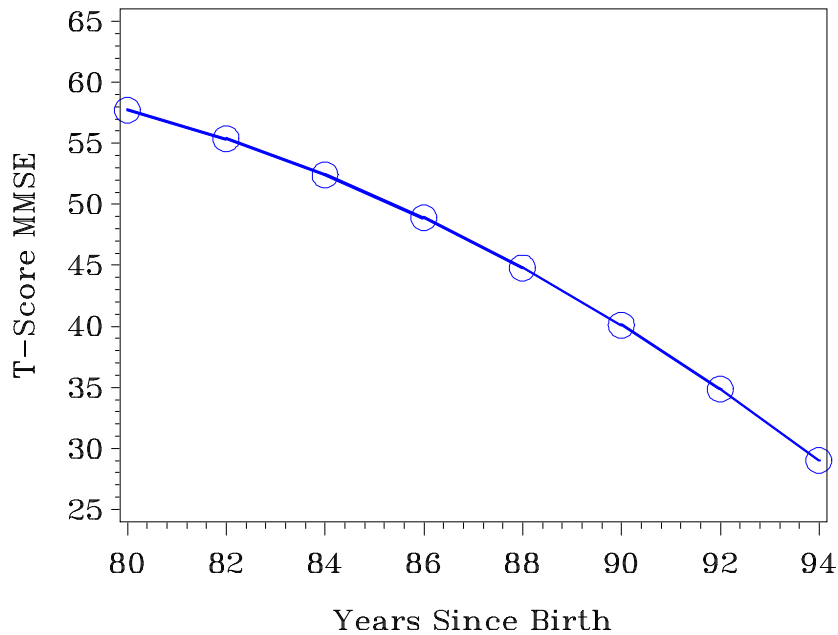
Significance → Nonconvergence

It matters **WHEN** you were 84

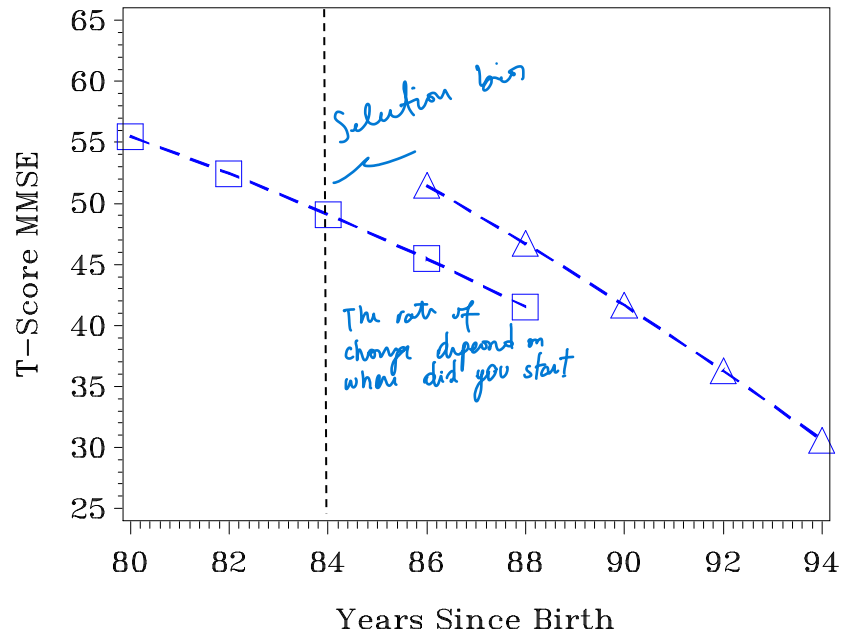
Persons create **contextual effects** (2022 update—captured only for the fixed age effects here!)

Age-Based Models: MMSE

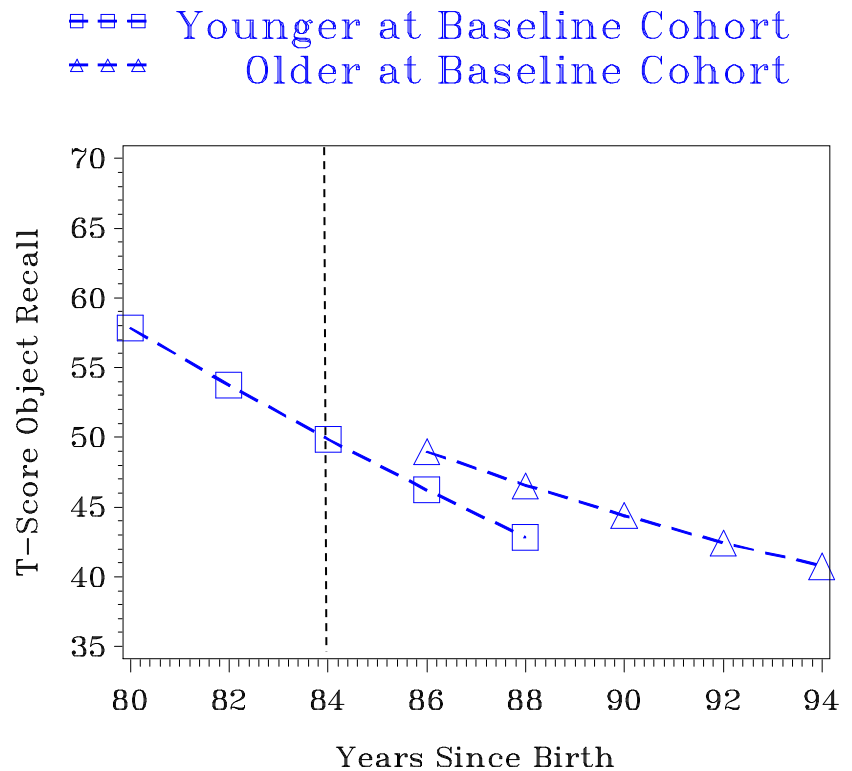
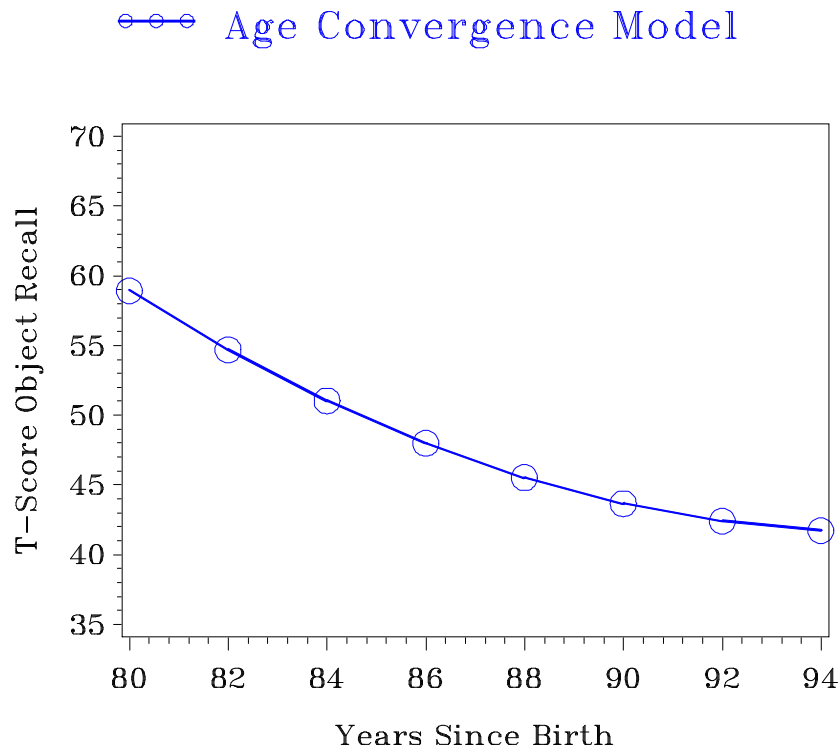
○—○ Age Convergence Model



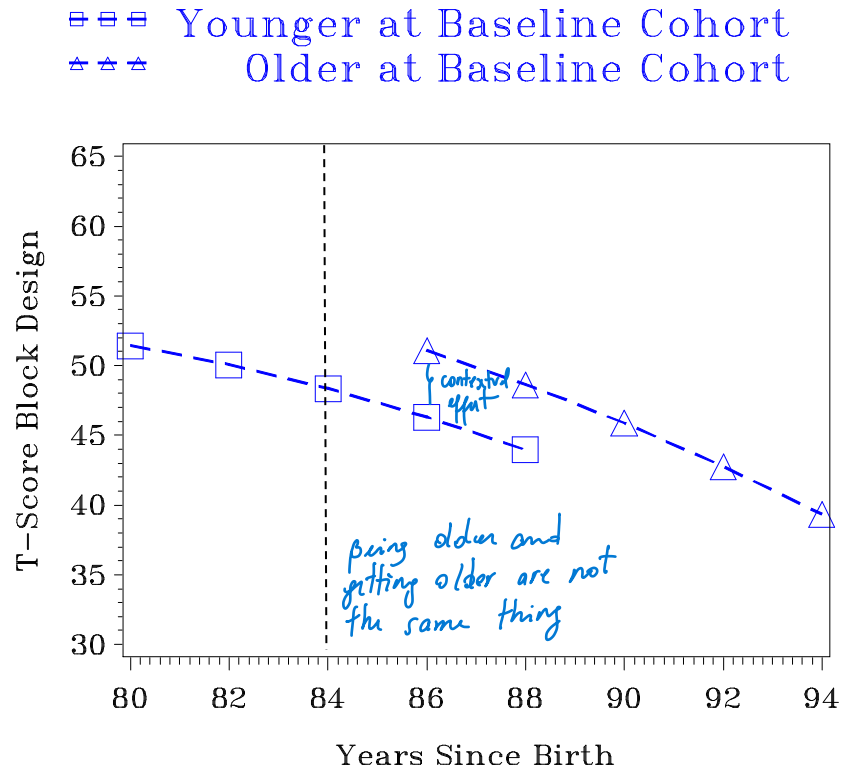
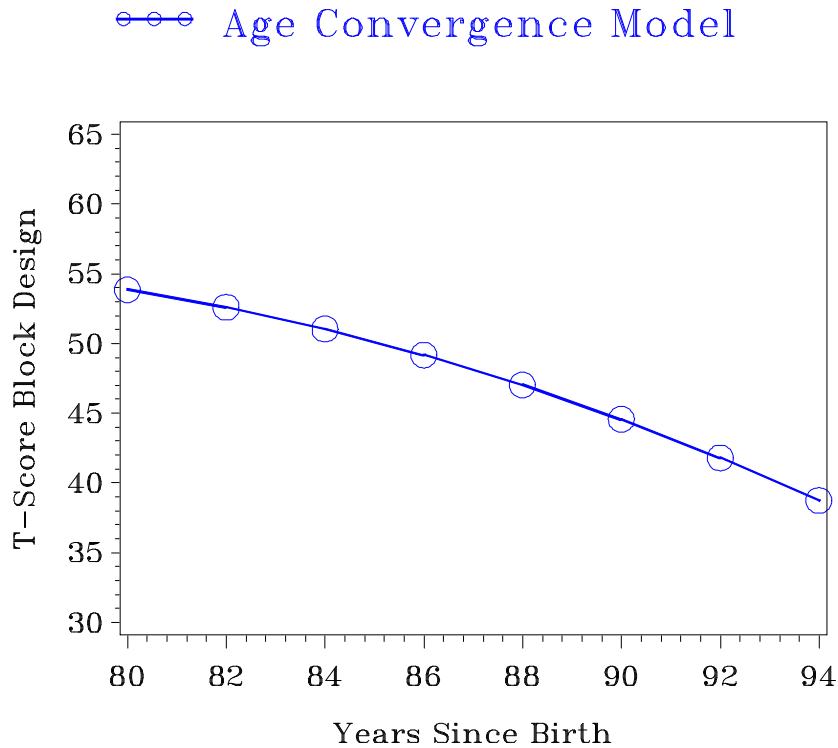
□—□ Younger at Baseline Cohort
△—△ Older at Baseline Cohort



Age-Based Models: Object Recall



Age-Based Models: Spatial Reasoning



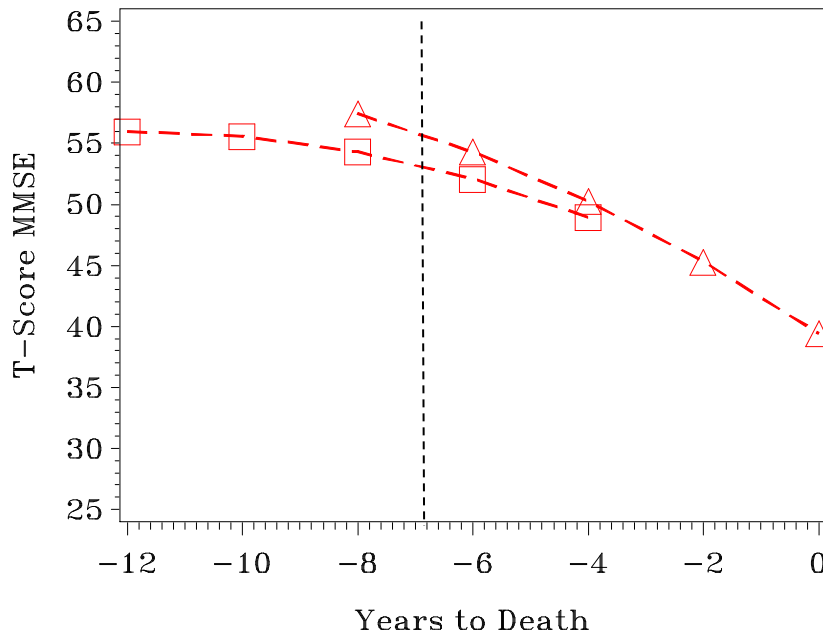
So if age is just a time-varying predictor...

- Because **years to death** and **years to diagnosis** also have BP variation (24%, 70%), the same concerns about **testing convergence** apply to them, too
- **Years to death**
 - Level 1: $YTdeath_{ti} + 7$
 - Level 2: $YTdeathT1_i + 7$
- **Years to diagnosis**
 - Level 1: $YTdem_{ti} - 0$
 - Level 2: $YTdemT1_i - 0$
- If the level-2 effects in these models are significant, then:
 - **Years to death**: it matters **WHEN** you were 7 years from death
 - **Years to diagnosis**: it matters **WHEN** you were at diagnosis

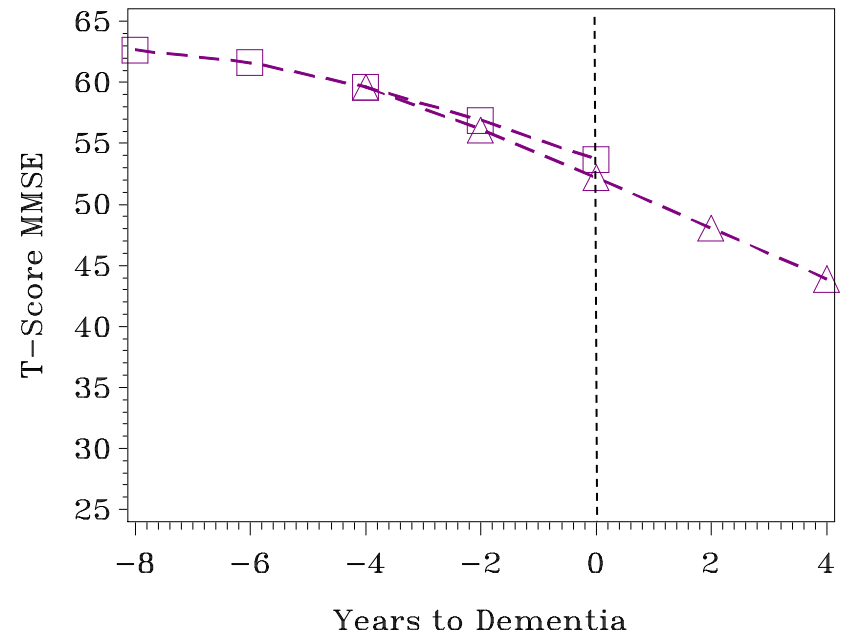
WHEN = cohort difference

Death-Based and Dementia-Based Models: MMSE

□ □ □ Further from Death Cohort
△ △ △ Closer to Death Cohort

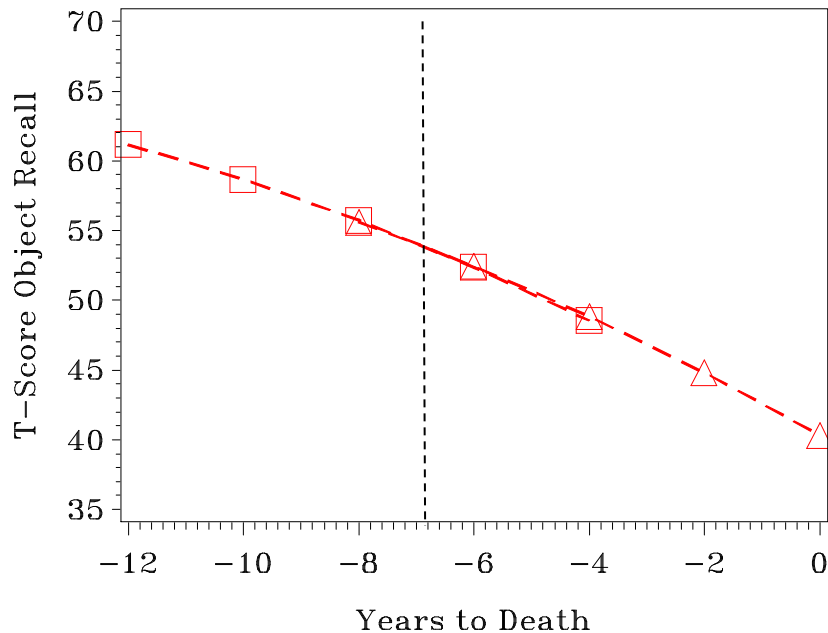


□ □ □ Further from Diagnosis Cohort
△ △ △ Closer to Diagnosis Cohort

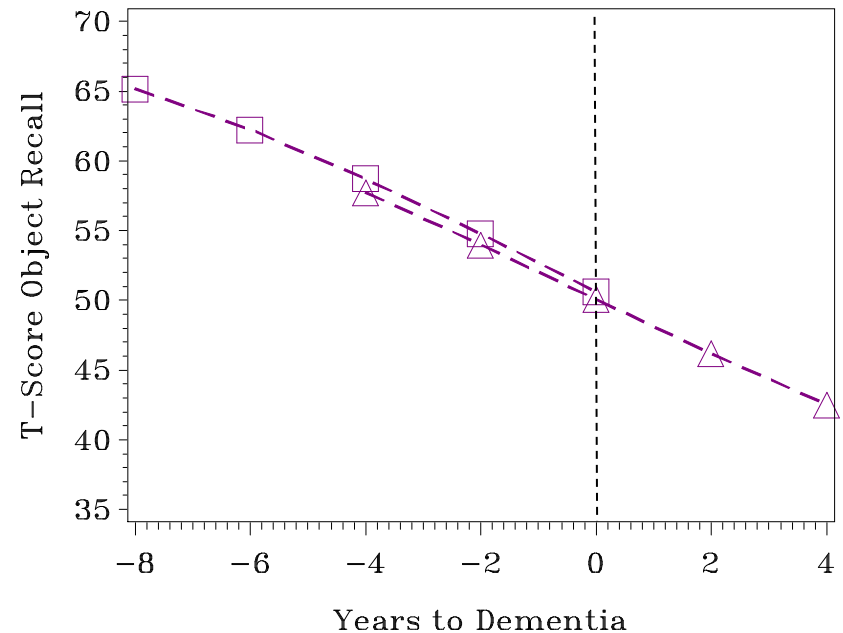


Death-Based and Dementia-Based Models: Object Recall

□ □ □ Further from Death Cohort
△ △ △ Closer to Death Cohort

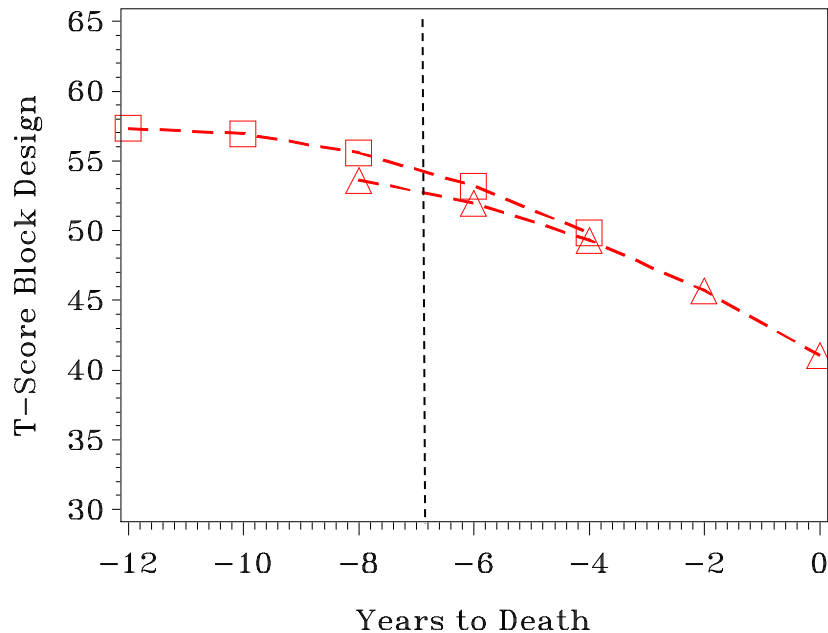


□ □ □ Further from Diagnosis Cohort
△ △ △ Closer to Diagnosis Cohort

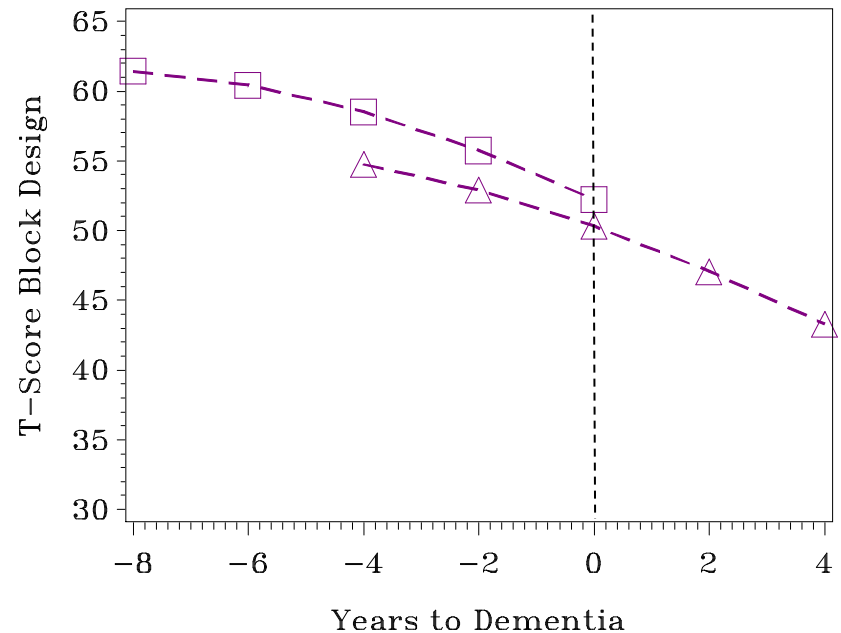


Death-Based and Dementia-Based Models: Spatial Reasoning

□ □ □ Further from Death Cohort
△ △ △ Closer to Death Cohort



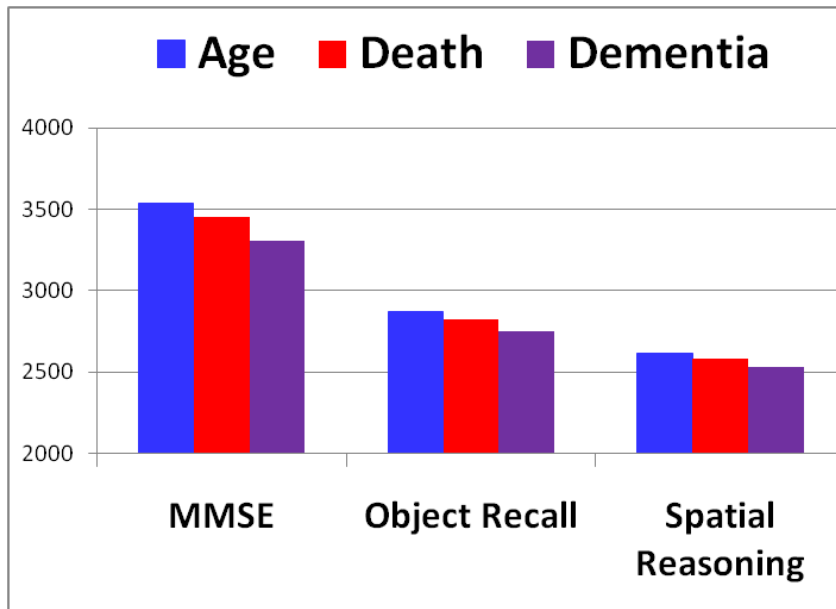
□ □ □ Further from Diagnosis Cohort
△ △ △ Closer to Diagnosis Cohort



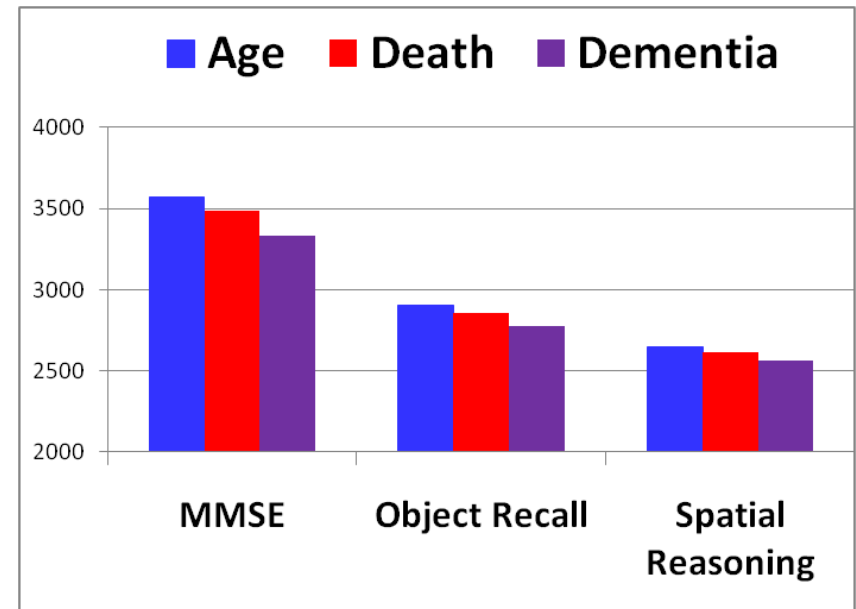
Comparing Models by Fit...

The fit of these alternative metrics of time to the data can be compared using their **information criteria**...

ML AIC



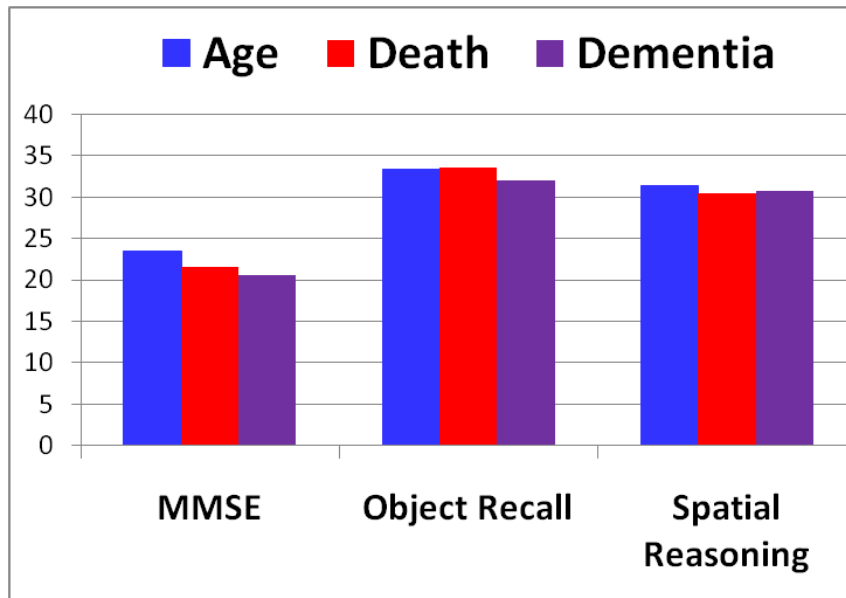
ML BIC



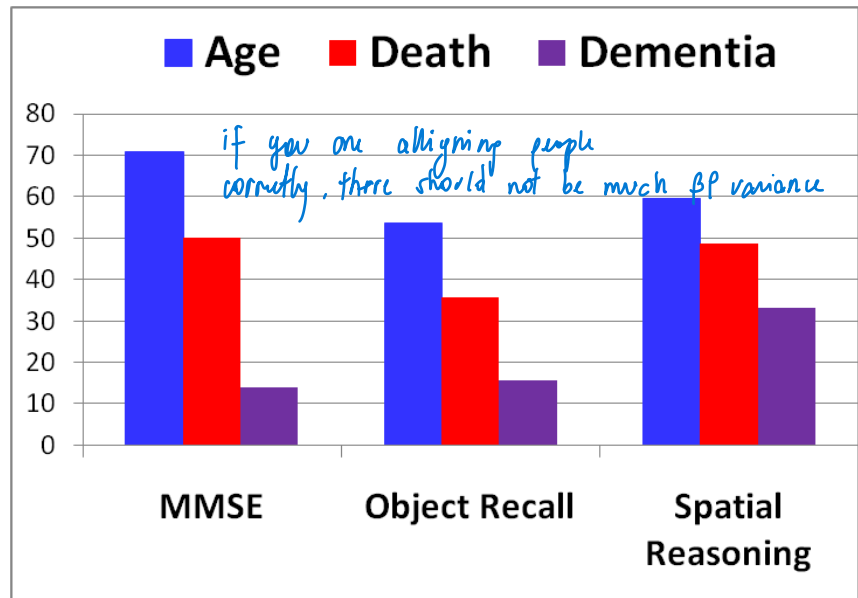
Comparing Models by Variances...

The fit of these alternative metrics of time to the data can also be compared using their **variance** components...

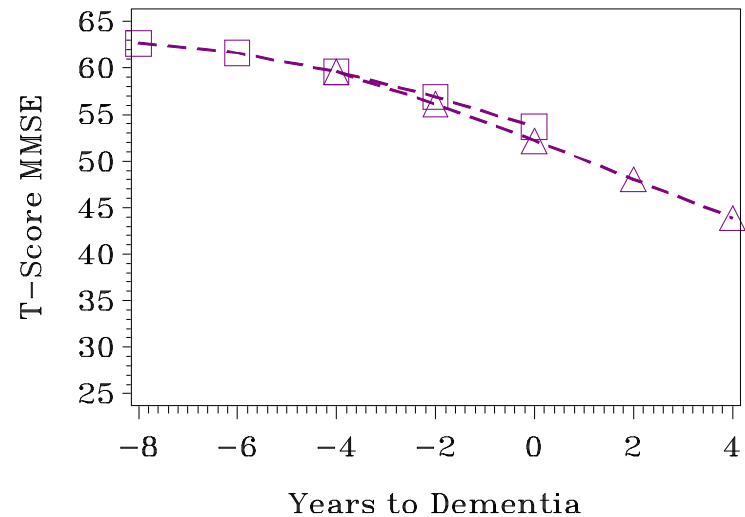
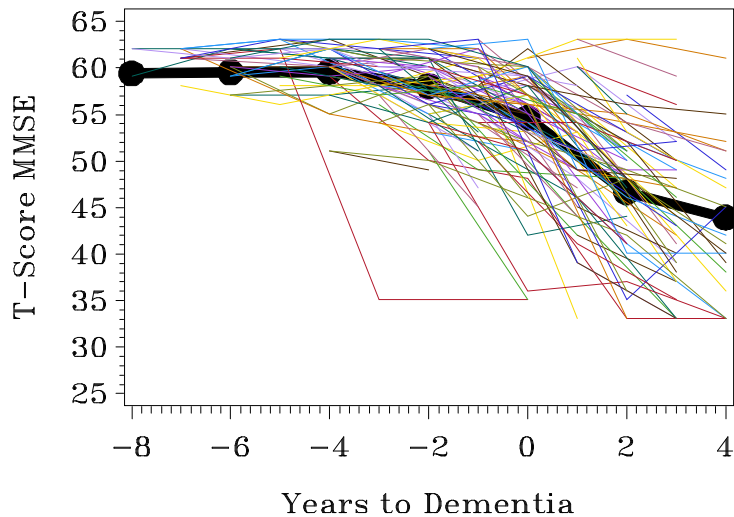
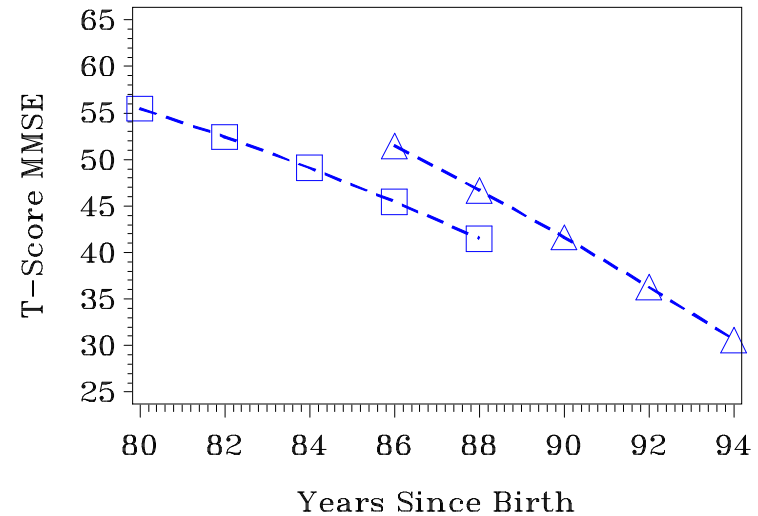
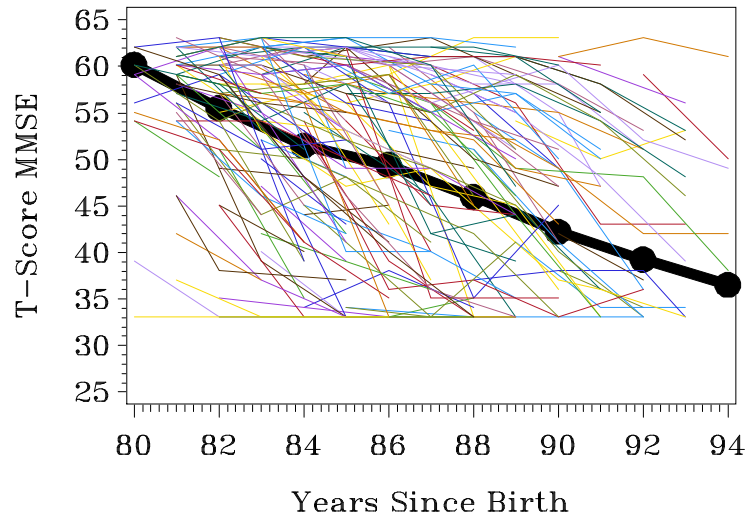
Residual Variance



Intercept Variance



Comparing Models By Data...



Road Map

- Steps in longitudinal analysis
- The missing step #2
- Example: Alternative metrics of “time”
- **What about just time?**
- What else contributes to “time”?

What about just time as “Time”?

- When the accelerated time metrics do not show convergence of their BP and WP time effects, an alternative model specification may be more useful
- **Time-in-study models** separate BP and WP effects
 - Accelerated time (age, death...) model → Grand-mean-centering
 - Time-in-study model → **Person/group-mean-centering**
- Time-in-study models **can be made equivalent** to models with accelerated time metric in their fixed effects, but not in their random effects (as shown shortly)

Just Time as “Time”

Original Age
Age _{ti}
80
82
84
80
82
84
84
86
88
84
86
88

Just Time as “Time”

BP Age	Original Age	WP Age
AgeT1 _i	Age _{ti}	Age _{ti} – AgeT1 _i
80	80	0
80	82	2
80	84	4
80	80	0
80	82	2
80	84	4
84	84	0
84	86	2
84	88	4
84	84	0
84	86	2
84	88	4

Just Time as “Time”

BP Age	Original Age	WP Age	Original YTD
AgeT1 _i	Age _{ti}	Age _{ti} – AgeT1 _i	YTdeath _{ti}
80	80	0	-12
80	82	2	-10
80	84	4	-8
80	80	0	-8
80	82	2	-6
80	84	4	-4
84	84	0	-12
84	86	2	-10
84	88	4	-8
84	84	0	-8
84	86	2	-6
84	88	4	-4

Just Time as “Time”

BP Age	Original Age	WP Age	BP Years to Death	Original YTD	WP Years to Death
AgeT1_i	Age_{ti}	$\text{Age}_{ti} - \text{AgeT1}_i$	YTdeathT1_i	YTdeath_{ti}	$\text{YTdeath}_{ti} - \text{YTdeathT1}_i$
80	80	0	-12	-12	0
80	82	2	-12	-10	2
80	84	4	-12	-8	4
80	80	0	-8	-8	0
80	82	2	-8	-6	2
80	84	4	-8	-4	4
84	84	0	-12	-12	0
84	86	2	-12	-10	2
84	88	4	-12	-8	4
84	84	0	-8	-8	0
84	86	2	-8	-6	2
84	88	4	-8	-4	4

Just Time as "Time"

Time:	BP Age	Original Age	WP Age	BP Years to Death	Original YTD	WP Years to Death
Years in Study	AgeT1_i	Age_{ti}	$\text{Age}_{ti} - \text{AgeT1}_i$	YTdeathT1_i	YTdeath_{ti}	$\text{YTdeath}_{ti} - \text{YTdeathT1}_i$
0	80	80	0	-12	-12	0
2	80	82	2	-12	-10	2
4	80	84	4	-12	-8	4
0	80	80	0	-8	-8	0
2	80	82	2	-8	-6	2
4	80	84	4	-8	-4	4
0	84	84	0	-12	-12	0
2	84	86	2	-12	-10	2
4	84	88	4	-12	-8	4
0	84	84	0	-8	-8	0
2	84	86	2	-8	-6	2
4	84	88	4	-8	-4	4

Model Variants Using Age

Level-1 Age-Based (Grand-MC):

$$y_{ti} = \beta_{0i} + \beta_{1i}(\text{Age}_{ti} - 84) + e_{ti}$$

Level-1 Time-Based (Person-MC):

$$y_{ti} = \beta_{0i} + \beta_{1i}(\text{Age}_{ti} - \text{AgeT1}_i) + e_{ti}$$

Same pattern would result in any other accelerated time metric (such as years to death)

Same Level-2 Equations:

$$\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{AgeT1}_i - 84) + U_{0i}$$

$$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{AgeT1}_i - 84) + U_{1i}$$

Level-2 AgeT1 effects:

Age-Based: Incremental effect of cross-sectional age
(**contextual** age cohort effect)

Time-Based: Total effect of cross-sectional age
(**between-person** age effect)

Effect of Age Cohort on Intercept (Fixed Level-1 Linear Age Slope)

Time-in-Study \approx Person-MC:

Level 1: $y_{ti} = \beta_{0i} + \beta_{1i}(\text{Age}_{ti} - \text{AgeT1}_i) + e_{ti}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{AT1}_i) + U_{0i}$

$$\beta_{1i} = \gamma_{10}$$

$$\rightarrow y_{ti} = \gamma_{00} + \gamma_{01}(\text{AT1}_i) + \gamma_{10}(\text{Age}_{ti} - \text{AT1}_i) + U_{0i} + e_{ti}$$

$$\rightarrow y_{ti} = \gamma_{00} + (\gamma_{01} - \gamma_{10})(\text{AT1}_i) + \gamma_{10}(\text{Age}_{ti}) + U_{0i} + e_{ti}$$

← In terms of **Time**

← In terms of **Age**

Age-Based \approx Grand-MC:

Level 1: $y_{ti} = \beta_{0i} + \beta_{1i}(\text{Age}_{ti}) + e_{ti}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{AT1}_i) + U_{0i}$

$$\beta_{1i} = \gamma_{10}$$

$$\rightarrow y_{ti} = \gamma_{00} + \gamma_{01}(\text{AT1}_i) + \gamma_{10}(\text{Age}_{ti}) + U_{0i} + e_{ti}$$

Term	Time	Age
Intercept	γ_{00}	γ_{00}
WP Effect	γ_{10}	γ_{10}
Contextual	$\gamma_{01} - \gamma_{10}$	γ_{01}
BP Effect	γ_{01}	$\gamma_{01} + \gamma_{10}$

Effect of Age Cohort on Level-1 Age Slope (Fixed Level-1 Linear Age Slope)

On left below: Time-in-Study \approx Person-MC:

Time as Time: $y_{ti} = \gamma_{00} + \gamma_{10}(\text{Age}_{ti} - \text{AT1}_i) + \gamma_{11}(\text{Age}_{ti} - \text{AT1}_i)(\text{AT1}_i) + \gamma_{01}(\text{AT1}_i) + \gamma_{02}(\text{AT1}_i^2) + U_{0i} + e_{ti}$

the quadratic effect is needed to disentangle the wp and bp moderation of the cohort effect

Time as Age: $y_{ti} = \gamma_{00} + \gamma_{10}(\text{Age}_{ti}) + \gamma_{11}(\text{Age}_{ti})(\text{AT1}_i) + (\gamma_{01} - \gamma_{10})(\text{AT1}_i) + (\gamma_{02} - \gamma_{11})(\text{AT1}_i^2) + U_{0i} + e_{ti}$

On right below: Age-Based \approx Grand-MC:

$$y_{ti} = \gamma_{00} + \gamma_{10}(\text{Age}_{ti}) + \gamma_{11}(\text{Age}_{ti})(\text{AT1}_i) + \gamma_{01}(\text{AT1}_i) + \gamma_{02}(\text{AT1}_i)^2 + U_{0i} + e_{ti}$$

Adding AgeT1²
creates equivalence

Intercept: $\gamma_{00} = \gamma_{00}$ BP Effect: $\gamma_{01} = \gamma_{01} + \gamma_{10}$ Cohort: $\gamma_{01} = \gamma_{01} - \gamma_{10}$

WP Effect: $\gamma_{10} = \gamma_{10}$ BP² Effect: $\gamma_{02} = \gamma_{02} + \gamma_{11}$ Cohort²: $\gamma_{02} = \gamma_{02} - \gamma_{11}$

BP*WP or Cohort*WP is the same: γ_{11}

Add Quadratic Level-1 Age Slope (Fixed Level-1 Age Slopes)

On left below: Time-in-Study \approx Person-MC:

$$\text{Time as Time: } y_{ti} = \gamma_{00} + \gamma_{10}(\text{Age}_{ti} - \text{AT1}_i) + \gamma_{20}(\text{Age}_{ti} - \text{AT1}_i)^2 \\ + \gamma_{11}(\text{Age}_{ti} - \text{AT1}_i)(\text{AT1}_i) + \gamma_{01}(\text{AT1}_i) + \gamma_{02}(\text{AT1}_i^2) + U_{0i} + e_{ti}$$

$$\text{Time as Age: } y_{ti} = \gamma_{00} + \gamma_{10}(\text{Age}_{ti}) + \gamma_{20}(\text{Age}_{ti}^2) + (\gamma_{11} - 2\gamma_{20})(\text{Age}_{ti})(\text{AT1}_i) \\ + (\gamma_{01} - \gamma_{10})(\text{AT1}_i) + (\gamma_{02} + \gamma_{20} - \gamma_{11})(\text{AT1}_i^2) + U_{0i} + e_{ti}$$

On right below: Age-Based \approx Grand-MC:

$$y_{ti} = \gamma_{00} + \gamma_{10}(\text{Age}_{ti}) + \gamma_{20}(\text{Age}_{ti})^2 + \gamma_{11}(\text{Age}_{ti})(\text{AT1}_i) \\ + \gamma_{01}(\text{AT1}_i) + \gamma_{02}(\text{AT1}_i)^2 + U_{0i} + e_{ti}$$

Intercept: $\gamma_{00} = \gamma_{00}$

BP Effect: $\gamma_{01} = \gamma_{01} + \gamma_{10}$

Cohort: $\gamma_{01} = \gamma_{01} - \gamma_{10}$

WP Effect: $\gamma_{10} = \gamma_{10}$

BP² Effect: $\gamma_{02} = \gamma_{02} + \gamma_{11} + \gamma_{20}$

Cohort²: $\gamma_{02} = \gamma_{02} - \gamma_{11} + \gamma_{20}$

WP² Effect: $\gamma_{20} = \gamma_{20}$

BP*WP: $\gamma_{11} = \gamma_{11} + 2\gamma_{20}$

Cohort*WP: $\gamma_{11} = \gamma_{11} - 2\gamma_{20}$

Time-in-Study Models so far...

- Specify WP change using only longitudinal information
- Are equivalent within persons across accelerated time metrics
- Because unique information from the alternative time metrics is really only available BP, it only shows up in the level-2 model
- Can (usually) be made equivalent in their fixed effects to models based in alternative accelerated time metrics
- **So why make a distinction? Different random effects...**

Random Slopes Across Models

Time-in-Study \approx Person-MC:

as Time: $y_{ti} = \gamma_{00} + \gamma_{10}(\text{Age}_{ti} - \text{AT1}_i) + \gamma_{01}(\text{AT1}_i) + U_{0i} + U_{1i}(\text{Age}_{ti} - \text{AT1}_i) + e_{ti}$

as Age: $y_{ti} = \gamma_{00} + \gamma_{10}(\text{Age}_{ti}) + (\gamma_{01} - \gamma_{10})(\text{AT1}_i) + U_{0i} + \boxed{U_{1i}(\text{Age}_{ti}) - U_{1i}(\text{AT1}_i)} + e_{ti}$ → will only apply to the within part

Age-Based \approx Grand-MC:

$$y_{ti} = \gamma_{00} + \gamma_{10}(\text{Age}_{ti}) + \gamma_{01}(\text{AT1}_i) + U_{0i} + \boxed{U_{1i}(\text{Age}_{ti})} + e_{ti}$$

So which do we choose?

Variance due to AT1_i is still part of the random slope in the age-based model. So the time-based and age-based models cannot be made equivalent in terms of random effects variances.

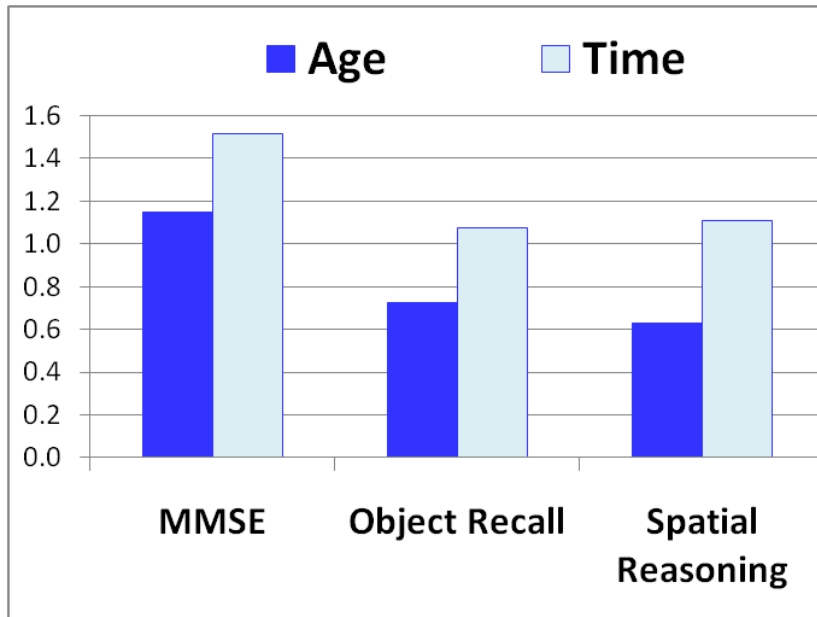
Random Slopes Across Models

- **Random intercepts** mean different things under each model:
 - **Time: Person-MC** → Individual differences at **time=0** (that everyone has)
 - **Age: Grand-MC** → Individual differences at **age=0** (that not everyone has)
- **Differential shrinkage of the random intercepts** results from differential reliability of the intercept data across models:
 - **Person-MC** → Won't affect shrinkage of slopes unless highly correlated
 - **Grand-MC** → Will affect shrinkage of slopes due to forced extrapolation
- As a result, the **random slope variance may be smaller** under **grand-MC (age, death...)** than under **person-MC (time)**
 - Problem worsens with greater BP variation in time (more extrapolation)
 - Anecdotal example of downward bias using clustered data was presented in Raudenbush & Bryk (2002; chapter 6), but what about in these data?
 - **2022 update: the age-as-time model assumes no contextual effect for the random age slope, whereas the time model does not—stay tuned!**

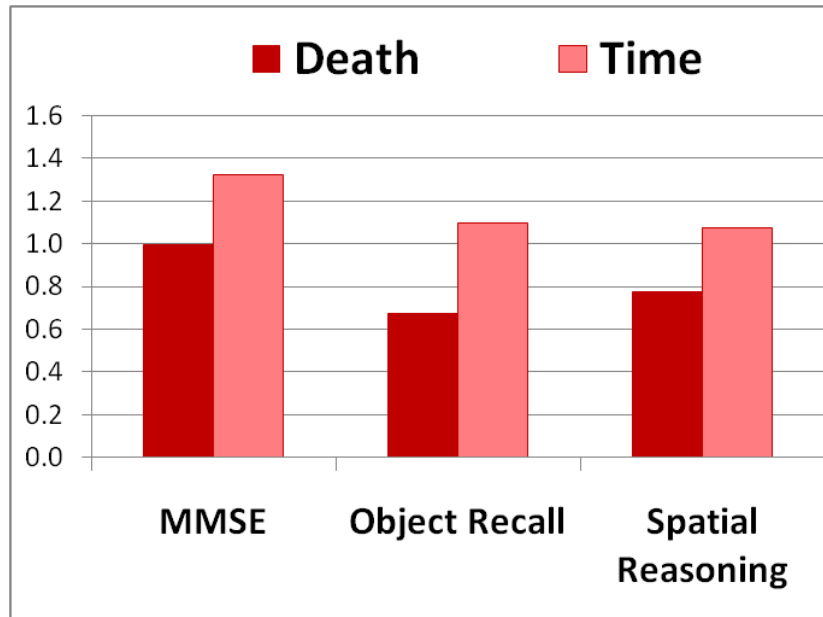
Slope Variance in Example Models

- Slope variance estimate was indeed **33-77% larger** in the time-based model versions across outcomes...

Years-Since-Birth (47% BP)

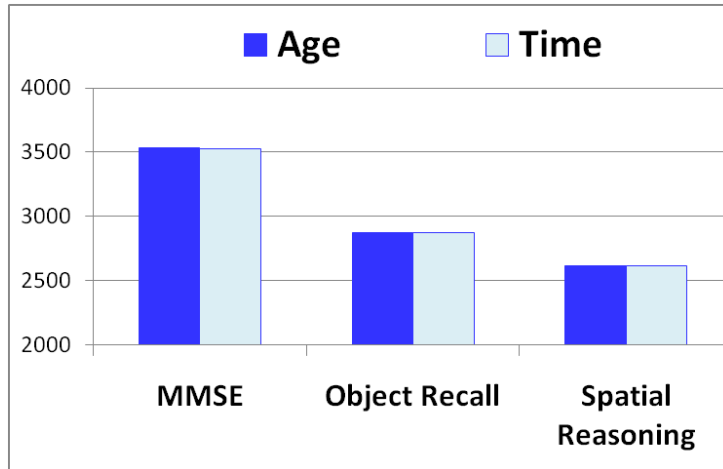


Years-to-Death (24% BP)

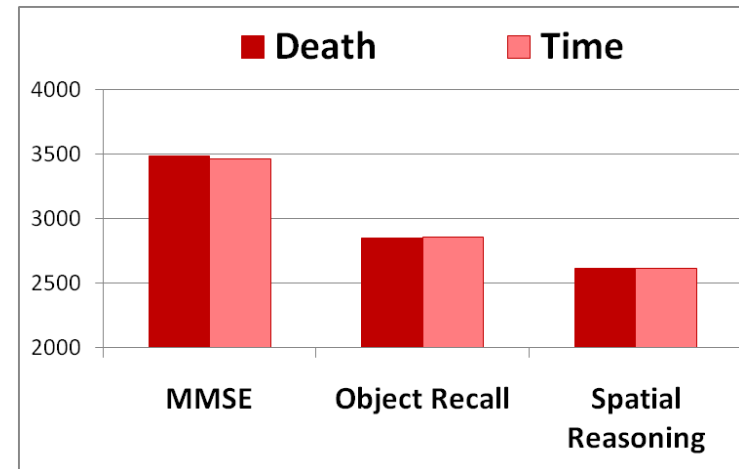
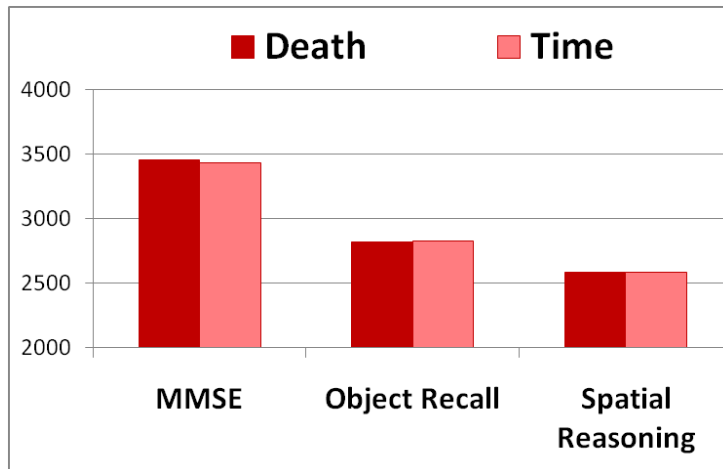
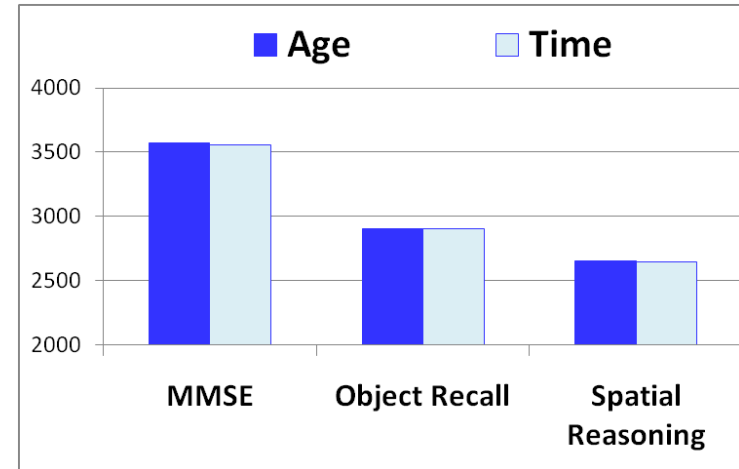


... Although model fit was the same

ML AIC



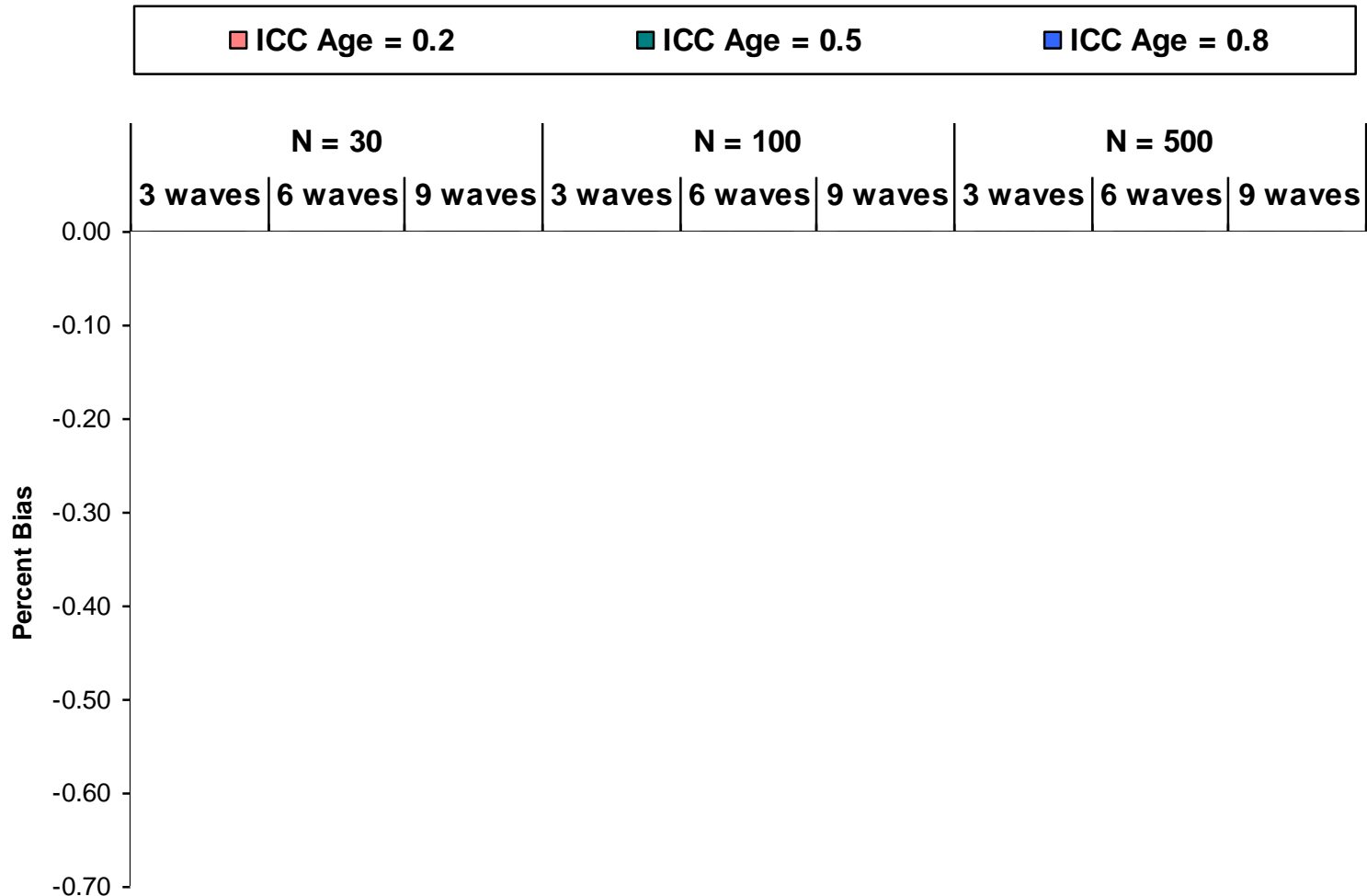
ML BIC



Simulation Study Results

(Generated by Time, Analyzed by Age)

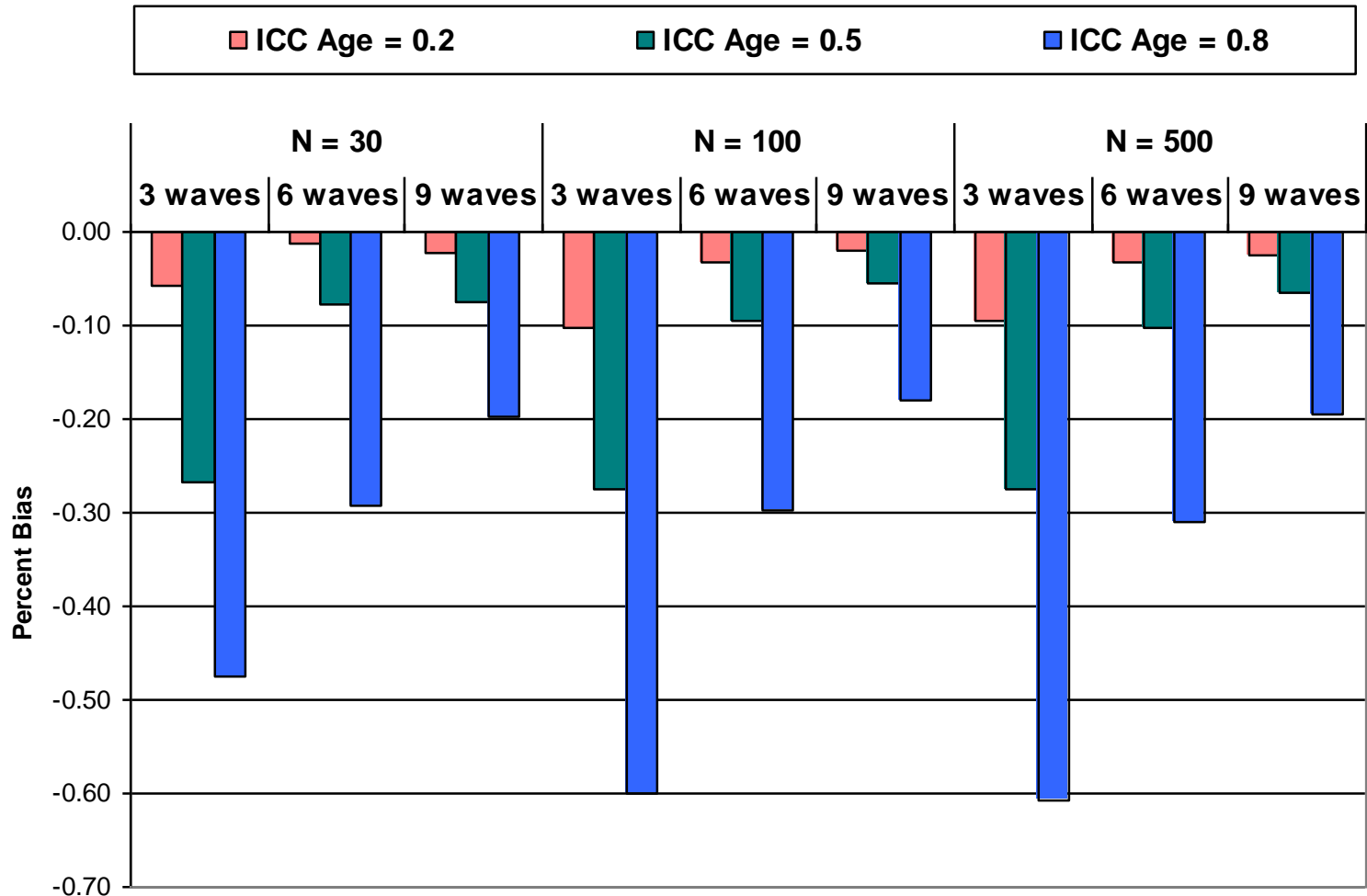
Percent Bias in Random Slope Variance



2008 Simulation Study Results

(Generated by Time, Analyzed by Age)

Percent Bias in Random Slope Variance



And so the winner is... Time?

- Although seemingly the most non-informative choice, simply tracking **change as a function of study duration**:
 - Represents **WP changes** as directly and parsimoniously as possible
 - Seems to recover **random slope variance** better in accelerated designs **(2022 update—because it doesn't assume no contextual effect!)**
 - Permits inclusion of persons who have not experienced events in an alternative time metric (e.g., death, dementia diagnosis) ↳ Conflected random effects
- Time-in-study models make no assumptions about processes causing change, so these become **testable hypotheses**
 - Do persons who are older start lower and decline faster?
 - *Age main effect, Age*Time interaction*
 - After considering mortality, do older persons *still* decline faster?
 - *Competing YTdeath*Time and Age*Time interactions*

Road Map

- Steps in longitudinal analysis
- The missing step #2
- Example: Alternative metrics of “time”
- What about just time?
- **What else contributes to “time”?**

What about retest effects?

- Are estimates of age-related change too small without controlling for **practice effects** due to repeated testing?
- Can **time-in-study** index **retest** in age-based models?

$$y_{ti} = \gamma_{00} + \gamma_{10}(\text{Age}_{ti}) + \gamma_{20}(\text{Age}_{ti})^2 \dots$$

$$+ e_{ti} + U_{0i} + \gamma_{1i}(\text{Age}_{ti}) + \dots$$

Individual change due to age

$$+ \gamma_{30}(\text{Retest}_{ti})$$

$$+ \gamma_{40}(\text{Retest}_{ti})(\text{Age}_{ti}) \dots$$

Retest = Time = Difference due to which occasion of measurement

- But not including age cohort assumes **age convergence**...
What if age cohort (AT1) and retest effects are BOTH included?
 - 2011 simulation results: missing cohort effects will masquerade as retest effects in the opposite direction—they are **confounded by design**

Conclusions

- When time has both BP and WP variation, one should always **carefully consider what “time” could and should be**
 - Otherwise, aggregate trends may not actually describe any individuals
 - Individual differences can be created artificially through the mis-alignment of different persons onto a single “time” trajectory
- **Multiple processes** may be at work simultaneously, but they have to be **observed independently** to be distinguishable
 - Age vs. Mortality: can be distinguished if not everyone dies at same age
 - But if **aging and retest occur simultaneously within-persons**, retest effects cannot be distinguished from effects of aging and age cohort
 - **Age/Cohort/Time** in design → **Age/Cohort/Retest** in models
- Considering the effects of time is an important pre-cursor to making informed use of advances in longitudinal models...

Thank you for your time...

- **Questions or comments? Please email me!**
- **Slides available at for download [on this page](#)**
- **Relevant Works:**
 - Hoffman, L., Hofer, S. M., & Sliwinski, M. J. (2011). On the confounds among retest gains and age-cohort differences in the estimation of within-person change in longitudinal studies: A simulation study. *Psychology and Aging*, 26(4), 778–791.
 - Hoffman, L. (2012). *Considering alternative metrics of time: Does anybody really know what “time” is?* In J. Harring & G. Hancock (Eds.), *Advances in Longitudinal Methods in the Social and Behavioral Sciences* (pp. 255–287). Information Age Publishing.
 - Hoffman, L., & Templin, J. L. (April, 2008). *The impact of alternative specifications of time on examining individual differences in change*. Poster presented at the Cognitive Aging Conference, Atlanta, GA.