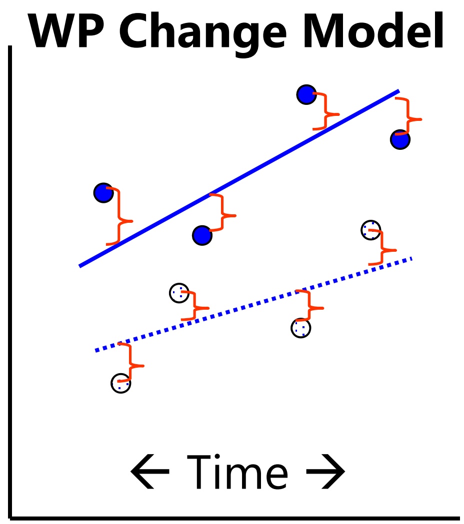
Time-Varying Predictors in Longitudinal Models

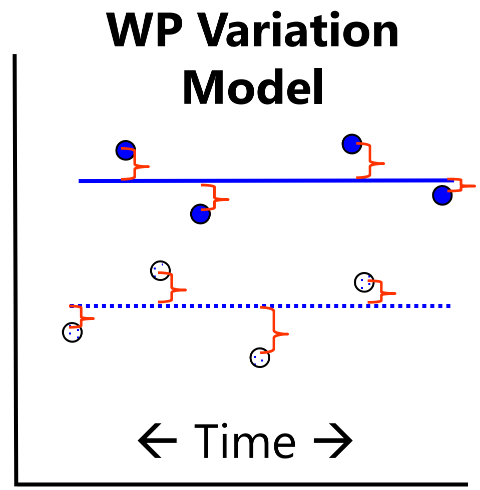
- Topics:
  - **Time-varying predictors that fluctuate over time**
  - Person-Mean-Centering (PMC)
  - Grand-Mean-Centering (GMC)
  - Model extensions under Person-MC vs. Grand-MC
  - Time-varying predictors that change over time

The Joy of Time-Varying Predictors

- TV predictors predict leftover **WP (residual) variation**:



If model for time works, then residuals should look like this →



- Modeling time-varying predictors is complicated because they represent an **aggregated effect**:
  - Effect of the *between-person* variation in the predictor x_{ti} on Y
  - Effect of the *within-person* variation in the predictor x_{ti} on Y
  - Here we are assuming the predictor x_{ti} only **fluctuates** over time…
    - *We will need a different model if x_{ti} changes systematically over time…*

The Joy of Time-Varying Predictors

- Time-varying (TV) predictors usually carry 2 kinds of effects because they are really 2 predictor variables, not 1

- Example: Stress measured daily
  - Some days are worse than others:
    - **WP variation in stress** *(represented as deviation from own mean)*
  - Some people just have more stress than others all the time:
    - **BP variation in stress** *(represented as person mean predictor over time)*

- Can quantify each source of variation with an ICC
  - ICC = (BP variance) / (BP variance + WP variance)
  - ICC > 0? TV predictor has BP variation (so it *could* have a BP effect)
  - ICC < 1? TV predictor has WP variation (so it *could* have a WP effect)

Between-Person vs. Within-Person Effects

- Between-person and within-person effects in <u>SAME</u> direction
  - Stress → Health?
    - **BP: People with more chronic stress than other people may have <u>worse</u> general health than people with less chronic stress**
    - **WP: People may feel <u>worse</u> than usual when they are currently under more stress than usual (regardless of what "usual" is)**
- Between-person and within-person effects in <u>OPPOSITE</u> directions
  - Exercise → Blood pressure?
    - **BP: People who exercise more often generally have <u>lower</u> blood pressure than people who are more sedentary**
    - **WP: During exercise, blood pressure is <u>higher</u> than during rest**
- Variables have different **meanings** at different levels!
- Variables have different **scales** at different levels

3 Kinds of Effects for TV Predictors

- **Is the Between-Person (BP) effect significant?**
  - Are people with higher predictor values <u>than other people</u> (*on average over time*) also higher on Y <u>than other people</u> (*on average over time*), such that the person mean of the TV predictor accounts for level-2 random intercept variance ($\tau^2_{U_0}$)?

- **Is the Within-Person (WP) effect significant?**
  - If you have higher predictor values <u>than usual</u> (*at this occasion*), do you also have higher outcomes values <u>than usual</u> (*at this occasion*), such that the within-person deviation of the TV predictor accounts for level-1 residual variance (σ^2_e)?

- **Are the BP and WP effects different sizes: Is there a contextual effect?**
  - After controlling for the absolute value of TV predictor at each occasion, is there still <u>an incremental contribution from having a higher person mean</u> of the TV predictor (i.e., does one's general tendency predict $\tau^2_{U_0}$ above and beyond)?
  - If there is no contextual effect, then the BP and WP effects of the TV predictor show <u>*convergence*</u>, such that their effects are of equivalent magnitude

Modeling TV Predictors (labeled as x_{ti})

- **Level-2 effect of x_{ti}:**
  - The level-2 effect of x_{ti} is usually represented by the person's mean of time-varying x_{ti} across time (labeled as **PMx$_i$** or $\mathbf{\bar{X}_i}$)
  - PMx$_i$ should be centered at a <u>CONSTANT</u> (grand mean or other) so that 0 is meaningful, just like any other time-invariant predictor

- **Level-1 effect of x_{ti} can be included two different ways:**
  - "**Group-mean-centering**" → "**<u>person-mean-centering</u>**" in longitudinal, in which level-1 predictors are centered using a <u>level-2 VARIABLE</u>
  - "**Grand-mean-centering**" → level-1 predictors are centered using a CONSTANT (not necessarily the grand mean; it's just called that)
  - Note that these 2 choices do NOT apply to the level-2 effect of x_{ti}!
    - But the interpretation of the level-2 effect of x_{ti} WILL DIFFER based on which centering method you choose for the level-1 effect of x_{ti}!

Time-Varying Predictors in Longitudinal Models

- Topics:
  - Time-varying predictors that fluctuate over time
  - **Person-Mean-Centering (PMC)**
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  - Model extensions under Person-MC vs. Grand-MC
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Person-Mean-Centering (P-MC)

- In P-MC, we decompose the TV predictor x_{ti} into 2 variables that directly represent its BP (level-2) and WP (level-1) sources of variation, and include those variables as the predictors instead:
- **Level-2, PM predictor = person mean of $\mathbf{x_{ti}}$**
  - $\mathbf{PMx_i} = \mathbf{\bar{X}_i} - \boldsymbol{C}$
  - $\mathrm{PMx_i}$ is centered at a constant C, chosen so 0 is meaningful
  - $\mathrm{PMx_i}$ is positive? Above sample mean → "more than other people"
  - $\mathrm{PMx_i}$ is negative? Below sample mean → "less than other people"
- **Level-1, WP predictor = deviation from person mean of $\mathbf{x_{ti}}$**
  - $\mathbf{WPx_{ti}} = \mathbf{x_{ti}} - \mathbf{\bar{X}_i}$ *(note: uncentered person mean $\boldsymbol{\bar{X}_i}$ is used to center x_{ti})*
  - $\mathrm{WPx_{ti}}$ is NOT centered at a constant; is centered at a VARIABLE
  - $\mathrm{WPx_{ti}}$ is positive? Above your own mean → "more than usual"
  - $\mathrm{WPx_{ti}}$ is negative? Below your own mean → "less than usual"

Within-Person Fluctuation Model with **Person-Mean-Centered Level-1 x_{ti}**

→ WP and BP Effects directly through **separate** parameters

x_{ti} is person-mean-centered into WPx_{ti}, with PMx_i at L2:

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

$WPx_{ti} = x_{ti} - \bar{X}_i$ → **it has only Level-1 WP variation**

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

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

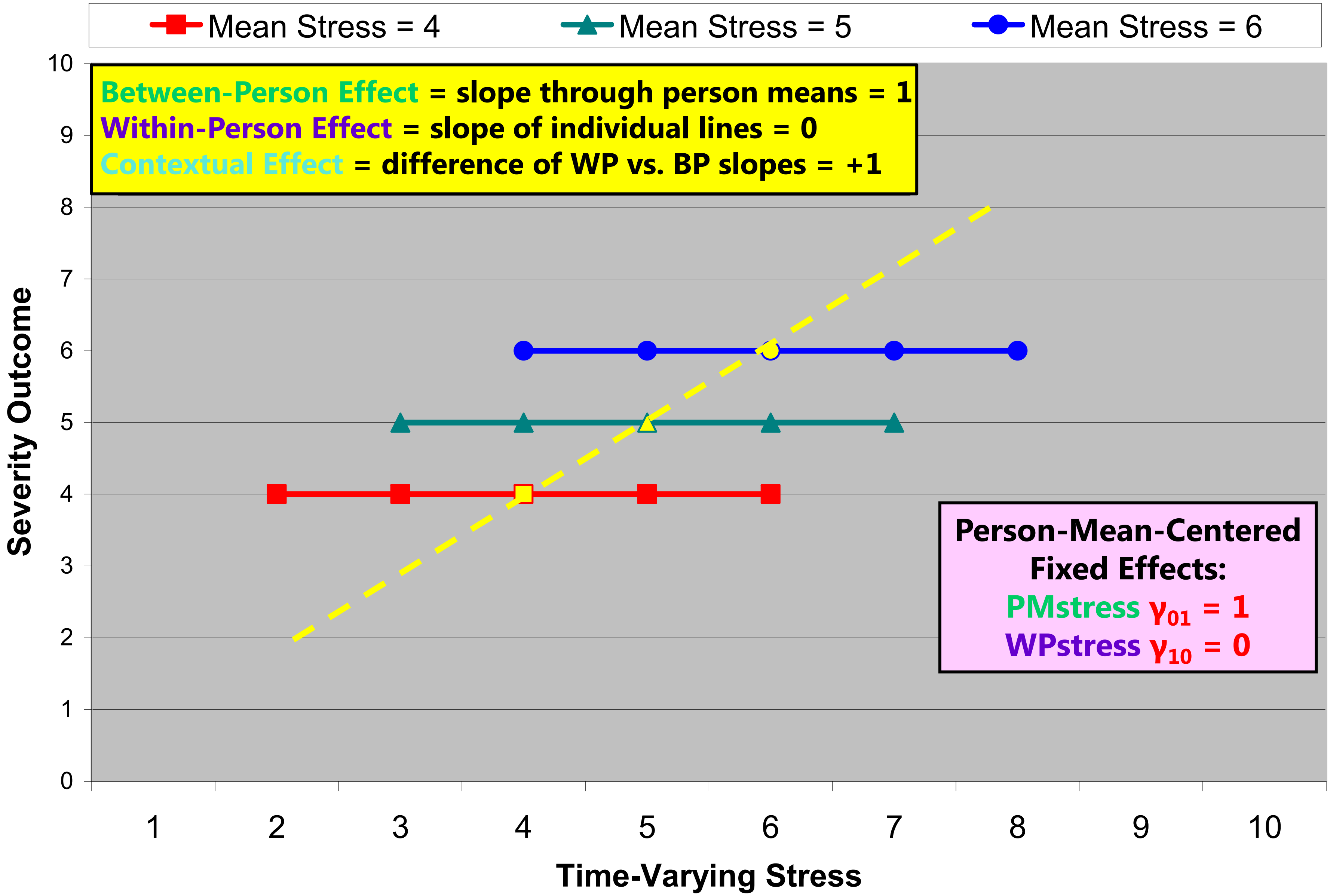
$PMx_i = \bar{X}_i - C$ → **it has only Level-2 BP variation**

γ_{10} = WP main effect of having more x_{ti} than usual

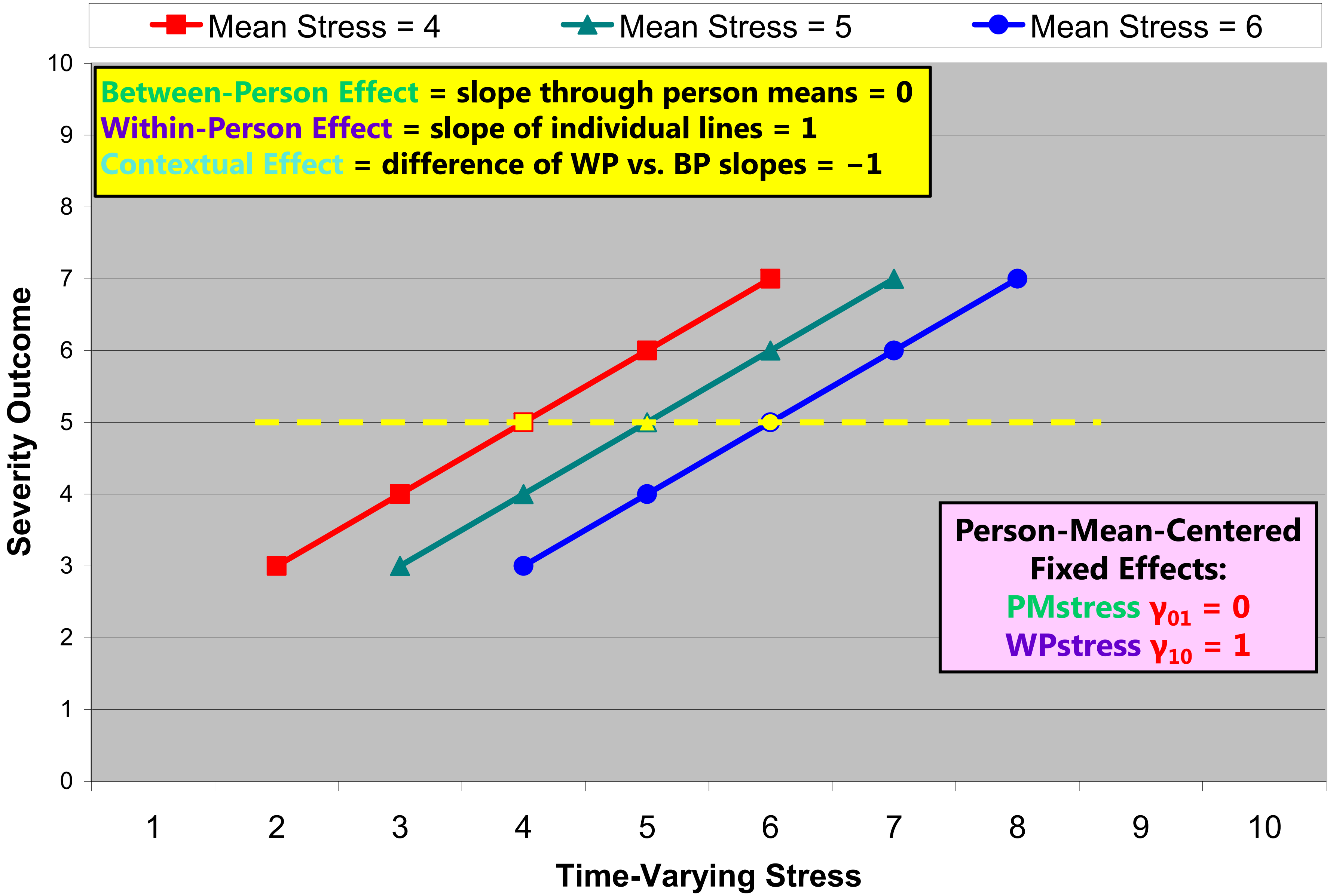
γ_{01} = BP main effect of having more $\bar{X}_i$ than other people

Because WPx_{ti} and PMx_i are uncorrelated, each gets the total effect for its level (WP=L1, BP=L2)

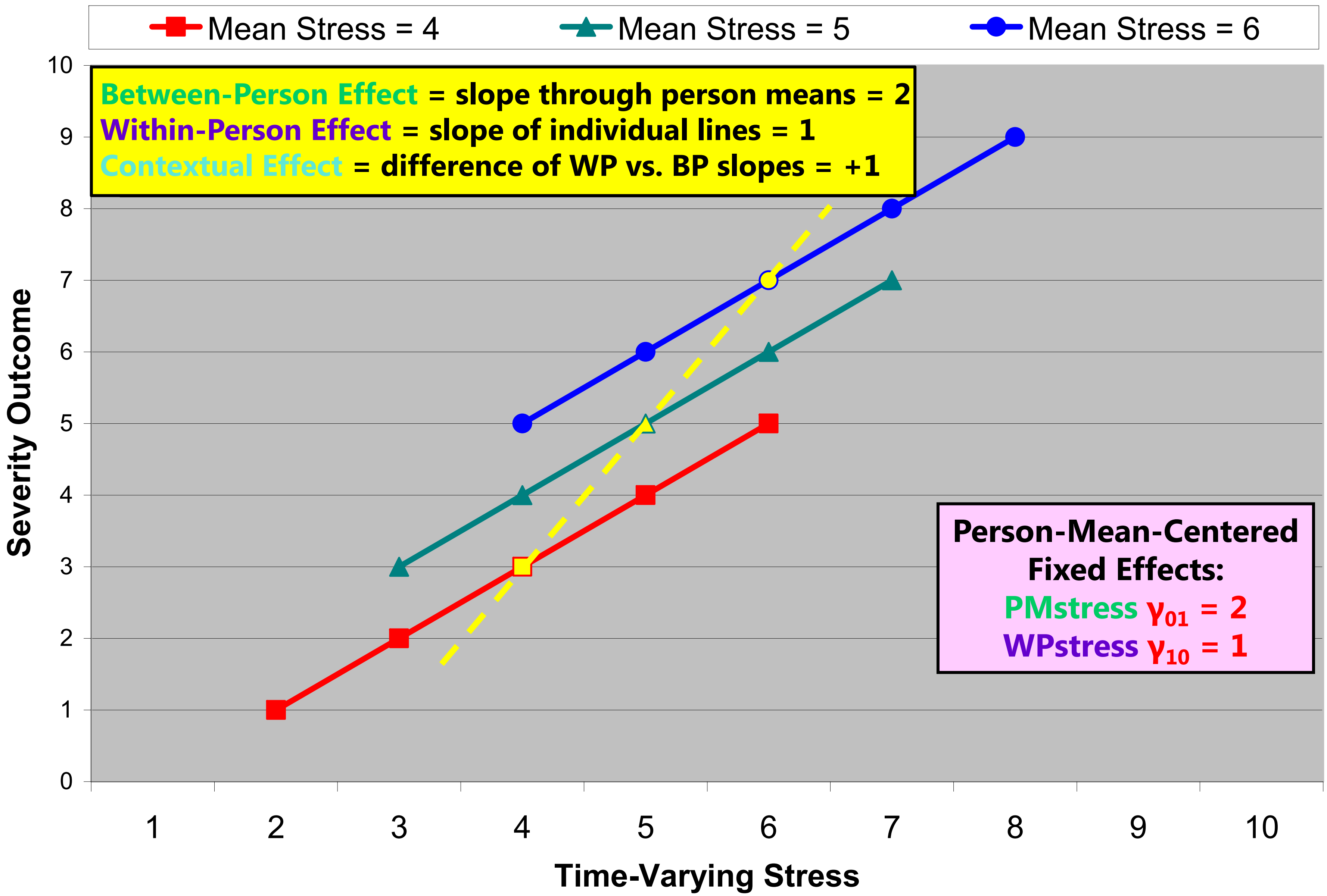
ALL Between-Person Effect, NO Within-Person Effect



NO Between-Person Effect, ALL Within-Person Effect



Between-Person Effect > Within-Person Effect



Within-Person Fluctuation Model with **Person-Mean-Centered Level-1 x_{ti}**

→ WP and BP Effects directly through **separate** parameters

x_{ti} is person-mean-centered into WPx_{ti}, with PMx_i at L2:

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

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

$\beta_{1i} = \gamma_{10} + \gamma_{11}(PMx_i) + U_{1i}$

$WPx_{ti} = x_{ti} - \bar{X}_i$ → it has only Level-1 WP variation

$PMx_i = \bar{X}_i - C$ → it has only Level-2 BP variation

U_{1i} is a random slope for the WP effect of x_{ti}

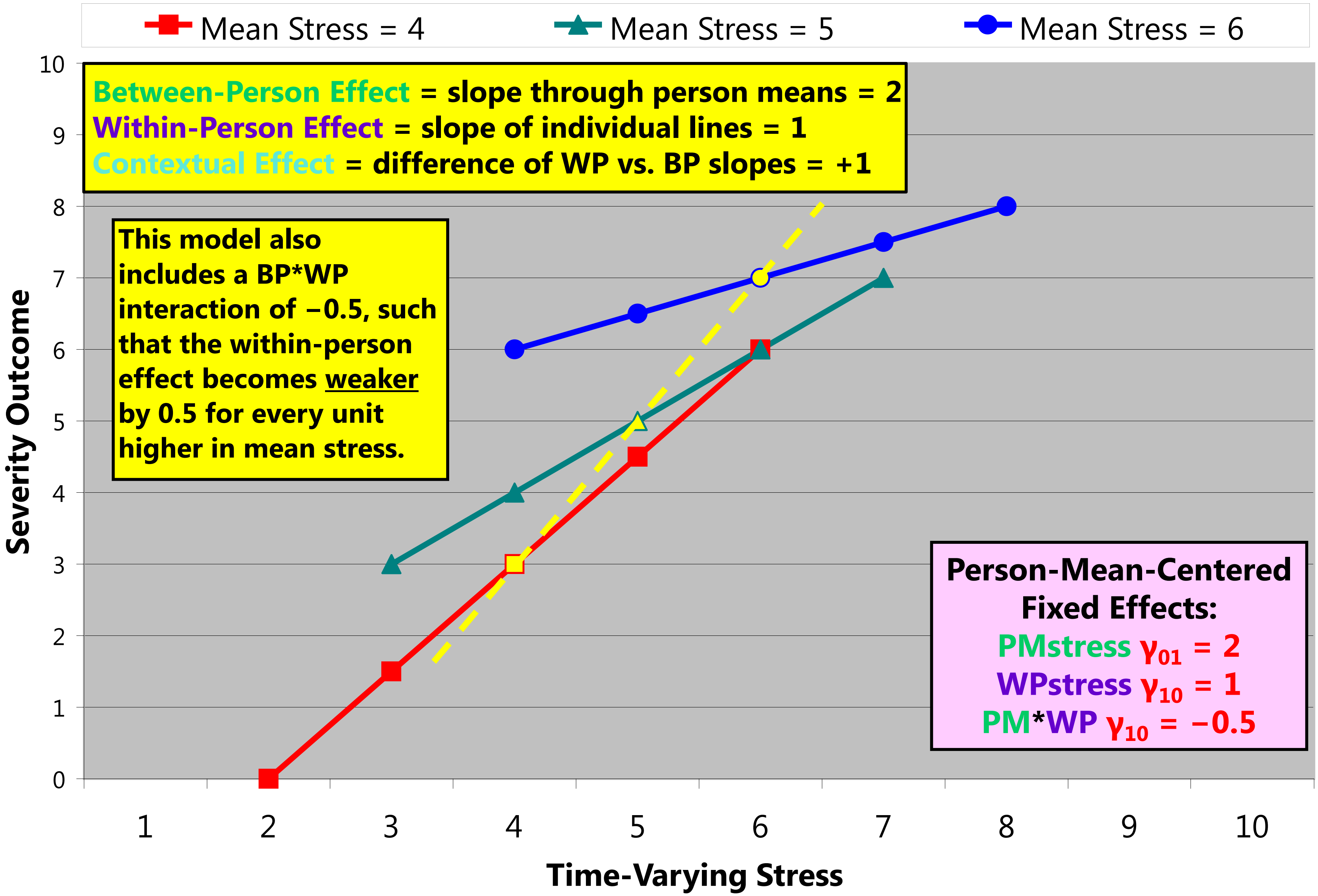
γ_{10} = WP simple main effect of having more x_{ti} than usual *for* $PMx_i = 0$

γ_{01} = BP simple main effect of having more $\bar{X}_i$ than other people for people at their own mean ($WPx_{ti} = x_{ti} - \bar{X}_i$ → 0)

γ_{11} = BP*WP interaction: how the effect of having more x_{ti} than usual differs by how much $\bar{X}_i$ you have

Note: this model should also test γ_{02} for $PMx_i * PMxi$ (stay tuned)

Between-Person x Within-Person Interaction



Time-Varying Predictors in Longitudinal Models

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3 Kinds of Effects for TV Predictors

- **What Person-Mean-Centering tells us <u>directly</u>:**

- **Is the Between-Person (BP) effect significant?**
  - Are people with higher predictor values <u>than other people</u> (*on average over time*) also higher on Y <u>than other people</u> (*on average over time*), such that the person mean of the TV predictor accounts for level-2 random intercept variance ($\tau^2_{U_0}$)?
  - This would be indicated by a significant fixed effect of $\mathbf{PMx_i}$
  - Note: this is NOT controlling for the absolute value of x_{ti} at each occasion

- **Is the Within-Person (WP) effect significant?**
  - If you have higher predictor values <u>than usual</u> (*at this occasion*), do you also have higher outcomes values <u>than usual</u> (*at this occasion*), such that the within-person deviation of the TV predictor accounts for level-1 residual variance (σ^2_e)?
  - This would be indicated by a significant fixed effect of $\mathbf{WPx_{ti}}$
  - Note: this is represented by the <u>relative</u> value of x_{ti}, NOT the <u>absolute</u> value of x_{ti}

3 Kinds of Effects for TV Predictors

- **What Person-Mean-Centering DOES NOT tell us <u>directly</u>:**

- **Are the BP and WP effects different sizes: Is there a contextual effect?**
  - After controlling for the absolute value of the TV predictor at each occasion, is there still <u>an incremental contribution from having a higher person mean of the TV predictor</u> (i.e., does one's general tendency predict $\tau^2_{U_0}$ above and beyond just the time-specific value of the predictor)?
  - If there is no contextual effect, then the BP and WP effects of the TV predictor show ***<u>convergence</u>***, such that their effects are of equivalent magnitude

- **To answer this question about the contextual effect for the incremental contribution of the person mean, we have two options:**
  - Ask for the contextual effect via an ESTIMATE statement in SAS (or TEST in SPSS, or NEW in Mplus, or LINCOM in STATA): $\mathbf{WPx_{ti}}$ -1 $\mathbf{PMx_{i}}$ 1
  - Use "**<u>grand-mean-centering</u>**" for time-varying x_{ti} instead: $\mathbf{TVx_{ti}} = \mathbf{x_{ti}} - \boldsymbol{C}$
    → **centered at a CONSTANT, NOT A LEVEL-2 VARIABLE**
    - Which constant only matters for what the reference point is; it could be the grand mean or other

Remember Regular Old Regression?

- In this model: $Y_i = \beta_0 + \beta_1(X_{1i}) + \beta_2(X_{2i}) + e_i$

  - If X_{1i} and X_{2i} **ARE NOT** correlated:
    - β_1 is **ALL the relationship** between X_{1i} and Y_i
    - β_2 is **ALL the relationship** between X_{2i} and Y_i

  - If X_{1i} and X_{2i} **ARE** correlated:
    - β_1 is **different than** the full relationship between X_{1i} and Y_i
      - "Unique" effect of X_{1i} *controlling for* X_{2i} or *holding* X_{2i} *constant*
    - β_2 is **different than** the full relationship between X_{2i} and Y_i
      - "Unique" effect of X_{2i} *controlling for* X_{1i} or *holding* X_{1i} *constant*

  - Hang onto that idea…

Person-MC vs. Grand-MC for Time-Varying Predictors

Level 2		Original	Person-MC Level 1	Grand-MC Level 1
$\bar{X}_i$	$PMx_i = \bar{X}_i - 5$	xti	$WPx_{ti} = x_{ti} - \bar{X}_i$	$TVx_{ti} = x_{ti} - 5$
3	−2	2	−1	−3
3	−2	4	1	−1
7	2	6	−1	1
7	2	8	1	3

Same PMx_i goes into the model using either way of centering the level-1 variable x_{ti}

Using **Person-MC**, WPx_{ti} has NO level-2 BP variation, so it is not correlated with PMx_i

Using **Grand-MC**, TVx_{ti} STILL has level-2 BP variation, so it is STILL CORRELATED with PMx_i

So the effects of PMx_i and TVx_{ti} when included together under Grand-MC will be different than their effects would be if they were by themselves…

Within-Person Fluctuation Model with $\mathbf{x_{ti}}$ represented at Level 1 Only:

→ WP and BP Effects are **Smushed Together**

x_{ti} is grand-mean-centered into TVx_{ti}, WITHOUT PMx_i at L2:

Level 1: $y_{ti} = \beta_{0i} + \beta_{1i}(\mathbf{TVx_{ti}}) + \mathbf{e_{ti}}$

$\mathrm{TVx_{ti}} = \mathrm{x_{ti}} - C$ → it still has both Level-2 BP and Level-1 WP variation

Level 2: $\beta_{0i} = \boldsymbol{\gamma_{00}} + \mathbf{U_{0i}}$

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

γ_{10} = *smushed* WP and BP effects

Because TVx_{ti} still contains its original 2 different kinds of variation (BP and WP), its 1 fixed effect has to do the work of 2 predictors!

A *smushed* effect is also referred to as the *convergence*, *conflated*, or *composite* effect

Convergence (Smushed) Effect of a Time-Varying Predictor

$$\text{Convergence Effect: } \gamma_{\text{conv}} \approx \frac{\dfrac{\gamma_{\text{BP}}}{\text{SE}^2_{\text{BP}}} + \dfrac{\gamma_{\text{WP}}}{\text{SE}^2_{\text{WP}}}}{\dfrac{1}{\text{SE}^2_{\text{BP}}} + \dfrac{1}{\text{SE}^2_{\text{WP}}}}$$

Adapted from Raudenbush & Bryk (2002, p. 138)

- **The convergence effect will often be closer to the within-person effect** (due to larger level-1 sample size and thus smaller SE)
- **It is the rule, not the exception, that between and within effects differ** (Snijders & Bosker, 1999, p. 52-56, and personal experience!)
- However—when grand-mean-centering a time-varying predictor, **convergence is testable** by including a **contextual effect (carried by the person mean)** for how the **BP effect** differs from the **WP effect**...

Within-Person Fluctuation Model with **Grand-Mean-Centered Level-1 x_{ti}**

→ Model tests difference of WP vs. BP effects (It's been fixed!)

x_{ti} is grand-mean-centered into TVx_{ti}, WITH PMx_i at L2:

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

$TVx_{ti} = x_{ti} - C$ → it still has both Level-2 BP and Level-1 WP variation

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

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

$PMx_i = \bar{X}_i - C$ → it has only Level-2 BP variation

γ_{10} becomes the WP effect → *unique* level-1 effect after controlling for PMx_i

γ_{01} *becomes* the contextual effect that indicates how the BP effect differs from the WP effect → *unique* level-2 effect after controlling for TVx_{ti} → does usual level matter beyond current level?

Person-MC and Grand-MC Models are Equivalent Given a Fixed Level-1 Main Effect Only

Person-MC: $WPx_{ti} = x_{ti} - PMx_i$

Level-1: $y_{ti} = \beta_{0i} + \beta_{1i}(x_{ti} - PMx_i) + e_{ti}$

Level-2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(PMx_i) + U_{0i}$

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

$\rightarrow y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti} - PMx_i) + U_{0i} + e_{ti}$

$\rightarrow y_{ti} = \gamma_{00} + (\gamma_{01} - \gamma_{10})(PMx_i) + \gamma_{10}(x_{ti}) + U_{0i} + e_{ti}$

Composite Model:
← In terms of P-MC
← In terms of G-MC

Grand-MC: $TVx_{ti} = x_{ti}$

Level-1: $y_{ti} = \beta_{0i} + \beta_{1i}(x_{ti}) + e_{ti}$

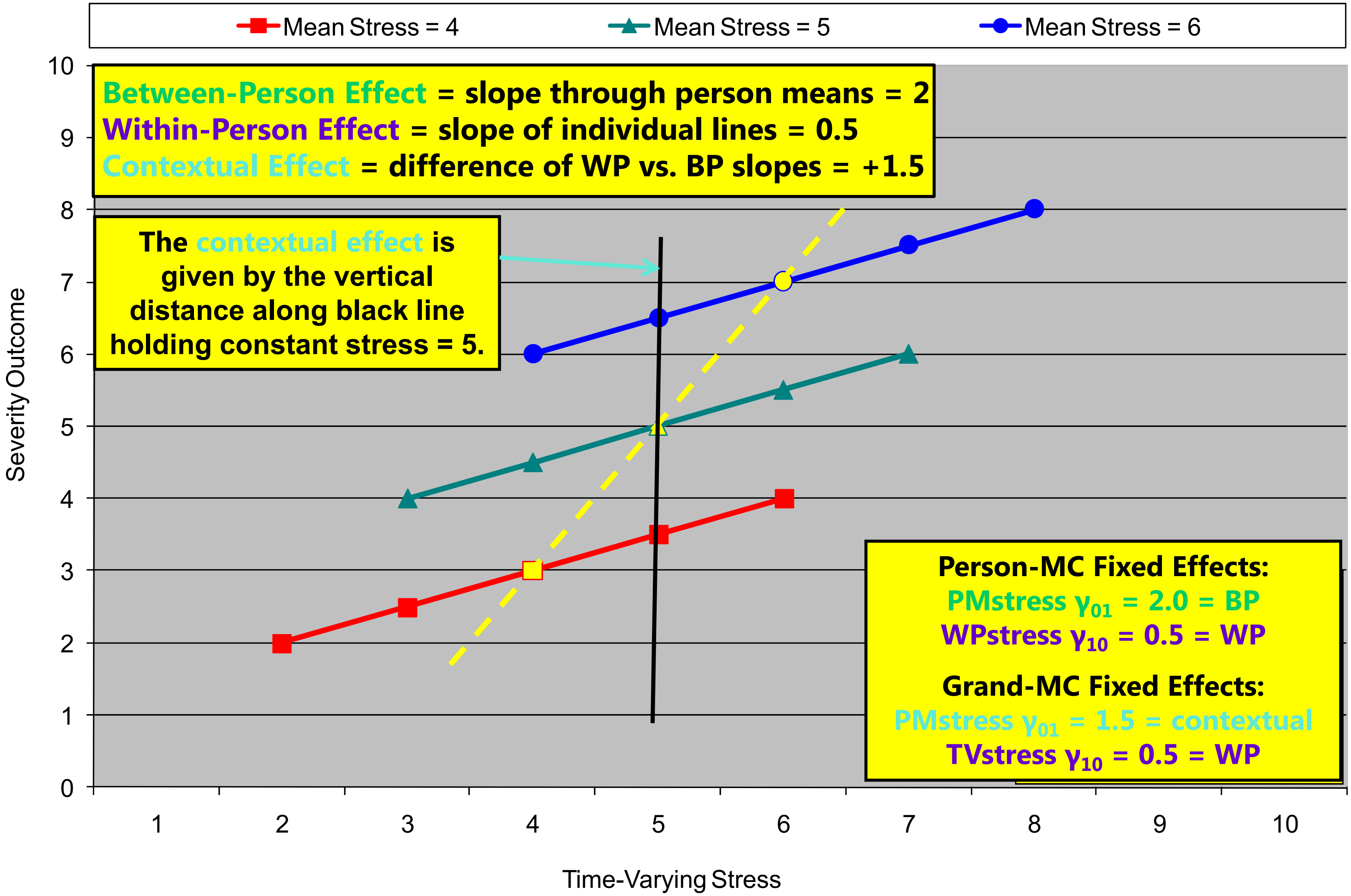
Level-2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(PMx_i) + U_{0i}$

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

$\rightarrow y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti}) + U_{0i} + e_{ti}$

Effect	P-MC	G-MC
Intercept	γ_{00}	γ_{00}
WP Effect	γ_{10}	γ_{10}
Contextual	$\gamma_{01} - \gamma_{10}$	γ_{01}
BP Effect	γ_{01}	$\gamma_{01} + \gamma_{10}$

P-MC vs. G-MC: Interpretation Example



Summary: 3 Effects for TV Predictors

- **Is the Between-Person (BP) effect significant?**
  - Are people with higher predictor values than other people (*on average over time*) also higher on Y than other people (*on average over time*), such that the person mean of the TV predictor accounts for level-2 random intercept variance ($\tau^2_{U_0}$)?
  - Given directly by level-2 effect of $\mathrm{PMx_i}$ if using Person-MC for the level-1 predictor (or can be requested via ESTIMATE if using Grand-MC for the level-1 predictor)

- **Is the Within-Person (WP) effect significant?**
  - If you have higher predictor values than usual (*at this occasion*), do you also have higher outcomes values than usual (*at this occasion*), such that the within-person deviation of the TV predictor accounts for level-1 residual variance (σ^2_e)?
  - Given directly by the level-1 effect of $\mathrm{WPx_{ti}}$ if using Person-MC —*OR* — given directly by the level-1 effect of $\mathrm{TVx_{ti}}$ if using Grand-MC and including $\mathrm{PMx_i}$ at level 2 (without $\mathrm{PMx_i}$, the level-1 effect of $\mathrm{TVx_{ti}}$ if using Grand-MC is the smushed effect)

- **Are the BP and WP Effects different sizes: Is there a contextual effect?**
  - After controlling for the absolute value of TV predictor value at each occasion, is there still an incremental contribution from having a higher person mean of the TV predictor (i.e., does one's general tendency predict $\tau^2_{U_0}$ above and beyond)?
  - Given directly by level-2 effect of $\mathrm{PMx_i}$ if using Grand-MC for the level-1 predictor (or can be requested via ESTIMATE if using Person-MC for the level-1 predictor)

Variance Accounted For By Level-1 Predictors

- **Fixed effects of level 1 predictors *by themselves*:**
  - Level-1 (WP) main effects reduce Level-1 (WP) residual variance
  - Level-1 (WP) interactions also reduce Level-1 (WP) residual variance

- **What happens at level 2 depends on what kind of variance the level-1 predictor has:**
  - If the level-1 predictor ALSO has level-2 variance (e.g., Grand-MC predictors), then its level-2 variance will also likely reduce level-2 random intercept variance
  - If the level-1 predictor DOES NOT have level-2 variance (e.g., Person-MC predictors), then its reduction in the level-1 residual variance will cause an INCREASE in level-2 random intercept variance
    - Same thing happens with Grand-MC level-1 predictors, but you don't generally see it
  - It's just an artifact that the estimate of true random intercept variance is:

    True $\tau^2_{U_0}$ = observed $\tau^2_{U_0} - \frac{\sigma^2_e}{n}$ → so if only σ^2_e decreases, $\tau^2_{U_0}$ increases

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The Joy of Interactions Involving Time-Varying Predictors

- Must consider interactions with both its BP and WP parts:
- Example: Does time-varying stress (x_{ti}) interact with sex (Sex_i)?

- Person-Mean-Centering:
  - $\mathbf{WPx_{ti}} * \mathbf{Sex_i}$ → Does the WP stress effect differ between men and women?
  - $\mathbf{PMx_i} * \mathbf{Sex_i}$ → Does the BP stress effect differ between men and women?
    - Not controlling for current levels of stress
    - If forgotten, then $\mathbf{Sex_i}$ moderates the stress effect only at level 1 (WP, not BP)

- Grand-Mean-Centering:
  - $\mathbf{TVx_{ti}} * \mathbf{Sex_i}$ → Does the WP stress effect differ between men and women?
  - $\mathbf{PMx_i} * \mathbf{Sex_i}$ → Does the *contextual* stress effect differ b/t men and women?
    - Incremental BP stress effect *after controlling for current levels of stress*
    - If forgotten, then although the level-1 main effect of stress has been un-smushed via the main effect of $\mathbf{PMx_i}$, the interaction of $\mathbf{TVx_{ti}} * \mathbf{Sex_i}$ would still be smushed

Interactions with Time-Varying Predictors: Example: TV Stress (x_{ti}) by Gender (Sex_i)

Person-MC: $WPx_{ti} = x_{ti} - PMx_i$

Level-1: $y_{ti} = \beta_{0i} + \beta_{1i}(x_{ti} - PMx_i) + e_{ti}$

Level-2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{02}(Sex_i) + \gamma_{03}(Sex_i)(PMx_i) + U_{0i}$

$\beta_{1i} = \gamma_{10} + \gamma_{11}(Sex_i)$

Composite: $y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti} - PMx_i) + U_{0i} + e_{ti}$
$+ \gamma_{02}(Sex_i) + \gamma_{03}(Sex_i)(PMx_i) + \gamma_{11}(Sex_i)(x_{ti} - PMx_i)$

Grand-MC: $TVx_{ti} = x_{ti}$

Level-1: $y_{ti} = \beta_{0i} + \beta_{1i}(x_{ti}) + e_{ti}$

Level-2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{02}(Sex_i) + \gamma_{03}(Sex_i)(PMx_i) + U_{0i}$

$\beta_{1i} = \gamma_{10} + \gamma_{11}(Sex_i)$

Composite: $y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti}) + U_{0i} + e_{ti}$
$+ \gamma_{02}(Sex_i) + \gamma_{03}(Sex_i)(PMx_i) + \gamma_{11}(Sex_i)(x_{ti})$

Interactions Involving Time-Varying Predictors Belong at Both Levels of the Model

On the left below → Person-MC: $WPx_{ti} = x_{ti} - PMx_i$

$$y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti} - PMx_i) + U_{0i} + e_{ti}$$
$$+ \gamma_{02}(Sex_i) + \gamma_{03}(Sex_i)(PMx_i) + \gamma_{11}(Sex_i)(x_{ti} - PMx_i)$$

← **Composite model written as Person-MC**

$$y_{ti} = \gamma_{00} + (\gamma_{01} - \gamma_{10})(PMx_i) + \gamma_{10}(x_{ti}) + U_{0i} + e_{ti}$$
$$+ \gamma_{02}(Sex_i) + (\gamma_{03} - \gamma_{11})(Sex_i)(PMx_i) + \gamma_{11}(Sex_i)(x_{ti})$$

← **Composite model written as Grand-MC**

On the right below → Grand-MC: $TVx_{ti} = x_{ti}$

$$y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti}) + U_{0i} + e_{ti}$$
$$+ \gamma_{02}(Sex_i) + \gamma_{03}(Sex_i)(PMx_i) + \gamma_{11}(Sex_i)(x_{ti})$$

After adding an interaction for Sex_i with stress at both levels, then the Person-MC and Grand-MC models are equivalent

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

WP Effect: $\gamma_{10} = \gamma_{10}$ **BP*Sex Effect:** $\gamma_{03} = \gamma_{03} + \gamma_{11}$ **Contextual*Sex:** $\gamma_{03} = \gamma_{03} - \gamma_{11}$

Sex Effect: $\gamma_{20} = \gamma_{20}$ **BP*WP or Contextual*WP is the same:** $\gamma_{11} = \gamma_{11}$

Intra-variable Interactions

- Still must consider interactions with both its BP and WP parts!
- Example: Interaction of TV stress (x_{ti}) with person mean stress (PMx_i)

- Person-Mean-Centering:
  - $\mathbf{WPx_{ti}} * \mathbf{PMx_i}$ → Does the WP stress effect differ by overall stress level?
  - $\mathbf{PMx_i} * \mathbf{PMx_i}$ → Does the BP stress effect differ by overall stress level?
    - Not controlling for current levels of stress
    - If forgotten, then $\mathbf{PMx_i}$ moderates the stress effect only at level 1 (WP, not BP)

- Grand-Mean-Centering:
  - $\mathbf{TVx_{ti}} * \mathbf{PMx_i}$ → Does the WP stress effect differ by overall stress level?
  - $\mathbf{PMx_i} * \mathbf{PMx_i}$ → Does the *contextual* stress effect differ by overall stress?
    - Incremental BP stress effect *after controlling for current levels of stress*
    - If forgotten, then although the level-1 main effect of stress has been un-smushed via the main effect of $\mathbf{PMx_i}$, the interaction of $\mathbf{TVx_{ti}} * \mathbf{PMx_i}$ would still be smushed

Intra-variable Interactions:
Example: TV Stress (x_{ti}) by Person Mean Stress (PMx_i)

Person-MC: $WPx_{ti} = x_{ti} - PMx_i$

Level-1: $y_{ti} = \beta_{0i} + \beta_{1i}(x_{ti} - PMx_i) + e_{ti}$

Level-2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{02}(PMx_i)(PMx_i) + U_{0i}$

$\beta_{1i} = \gamma_{10} + \gamma_{11}(PMx_i)$

Composite: $y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti} - PMx_i) + U_{0i} + e_{ti}$
$+ \gamma_{02}(PMx_i)(PMx_i) + \gamma_{11}(PMx_i)(x_{ti} - PMx_i)$

Grand-MC: $TVx_{ti} = x_{ti}$

Level-1: $y_{ti} = \beta_{0i} + \beta_{1i}(x_{ti}) + e_{ti}$

Level-2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{02}(PMx_i)(PMx_i) + U_{0i}$

$\beta_{1i} = \gamma_{10} + \gamma_{11}(PMx_i)$

Composite: $y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti}) + U_{0i} + e_{ti}$
$+ \gamma_{02}(PMx_i)(PMx_i) + \gamma_{11}(PMx_i)(x_{ti})$

Intra-variable Interactions:
Example: TV Stress (x_{ti}) by Person Mean Stress (PMx_i)

On the left below → Person-MC: $WPx_{ti} = x_{ti} - PMx_i$

$y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti} - PMx_i) + U_{0i} + e_{ti}$
$+ \gamma_{02}(PMx_i)(PMx_i) + \gamma_{11}(PMx_i)(x_{ti} - PMx_i)$

← **Written as Person-MC**

$y_{ti} = \gamma_{00} + (\gamma_{01} - \gamma_{10})(PMx_i) + \gamma_{10}(x_{ti}) + U_{0i} + e_{ti}$
$+ (\gamma_{02} - \gamma_{11})(PMx_i)(PMx_i) + \gamma_{11}(PMx_i)(x_{ti})$

← **Written as Grand-MC**

On the right below → Grand-MC: $TVx_{ti} = x_{ti}$

$y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti}) + U_{0i} + e_{ti}$
$+ \gamma_{02}(PMx_i)(PMx_i) + \gamma_{11}(PMx_i)(x_{ti})$

After adding an interaction for PMx_i with stress at both levels, then the Person-MC and Grand-MC models are equivalent

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

WP Effect: $\gamma_{10} = \gamma_{10}$ **BP² Effect:** $\gamma_{02} = \gamma_{02} + \gamma_{11}$ **Contextual²:** $\gamma_{02} = \gamma_{02} - \gamma_{11}$

BP*WP or Contextual*WP is the same: $\gamma_{11} = \gamma_{11}$

When Person-MC ≠ Grand-MC: Random Effects of TV Predictors

Person-MC: $WPx_{ti} = x_{ti} - PMx_i$

Level-1: $y_{ti} = \beta_{0i} + \beta_{1i}(x_{ti} - PMx_i) + e_{ti}$

Level-2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(PMx_i) + U_{0i}$

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

Variance due to PMx_i is removed from the random slope in Person-MC.

$\rightarrow y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti} - PMx_i) + U_{0i} + U_{1i}(x_{ti} - PMx_i) + e_{ti}$

Grand-MC: $TVx_{ti} = x_{ti}$

Level-1: $y_{ti} = \beta_{0i} + \beta_{1i}(x_{ti}) + e_{ti}$

Level-2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(PMx_i) + U_{0i}$

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

Variance due to PMx_i is still part of the random slope in Grand-MC. So these models cannot be made equivalent.

$\rightarrow y_{ti} = \gamma_{00} + \gamma_{01}(PMx_i) + \gamma_{10}(x_{ti}) + U_{0i} + U_{1i}(x_{ti}) + e_{ti}$

Random Effects of TV Predictors

- **Random intercepts** mean different things under each model:
  - **Person-MC** → Individual differences at **WPx_{ti} =0** (that everyone has)
  - **Grand-MC** → Individual differences at **TVx_{ti}=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 too small** when using Grand-MC rather than Person-MC
  - Problem worsens with greater ICC of TV Predictor (more extrapolation)
  - Anecdotal example using clustered data was presented in Raudenbush & Bryk (2002; chapter 6)

Modeling Time-Varying Categorical Predictors

- Person-MC and Grand-MC really only apply to *continuous* TV predictors, but the need to consider BP and WP effects applies to *categorical* TV predictors too
- Binary level-1 predictors do not lend themselves to Person-MC
  - e.g., x_{ti} = 0 or 1 per occasion, person mean = .50 across occasions → impossible values
  - If x_{ti} = 0, then WPx_{ti} = 0 − .50 = − 0.50; If x_{ti} = 1, then WPx_{ti} = 1 − .50 = 0.50
  - Better: Leave x_{ti} uncentered and include person mean as level-2 predictor (results ~ Grand-MC)
- For >2 categories, person means of multiple dummy codes starts to break down, but we can think about types of people, and code BP effects accordingly
- Example: Dementia present/not at each time point?
  - **BP effects →** Ever diagnosed with dementia (no, yes)?
    - People who will eventually be diagnosed may differ prior to diagnosis (a BP effect)
  - **TV effect →** Diagnosed with dementia at each time point (no, yes)?
    - Acute differences of before/after diagnosis logically can only exist in the "ever" people
- Other examples: Mentor status, father absence, type of shift work (AM/PM)

Wrapping Up: Person-MC vs. Grand-MC

- Time-varying predictors carry at least two potential effects:
  - Some people are higher/lower than other people → BP, level-2 effect
  - Some occasions are higher/lower than usual → WP, level-1 effect

- BP and WP effects almost always need to be represented by two or more model parameters, using either:
  - *Person-mean-centering* (WPx_{ti} and PMx_i): WP ≠ 0?, BP ≠ 0?
  - *Grand-mean-centering* (TVx_{ti} and PMx_i): WP ≠ 0?, BP ≠ WP?
  - Both yield equivalent models if the level-1 WP effect is fixed, but not if the level-1 WP effect is random
    - Grand MC → *absolute* effect of x_{ti} varies randomly over people
    - Person MC → *relative* effect of x_{ti} varies randomly over people
    - Use prior theory and empirical data (ML AIC, BIC) to decide

Time-Varying Predictors in Longitudinal Models

- Topics:
  - Time-varying predictors that fluctuate over time
  - Person-Mean-Centering (PMC)
  - Grand-Mean-Centering (GMC)
  - Model extensions under Person-MC vs. Grand-MC
  - **Time-varying predictors that change over time**

Baseline Centering for Time-Varying Predictors that Change over Time

- Although using the person mean of the time-varying predictor at level-2 (PMx_i) is the most common way to represent the effect of between-person differences, there are other options that sometimes can be more useful

- **Level-2 → X at centering point of time (e.g., x_{ti} at time 0)**
  - Useful if x_{ti} at specific time point conveys useful information, such as baseline level of a covariate in an intervention
  - Useful if x_{ti} is expected to change systematically over time, too

- Create predictors using a variant of PMC → **baseline centering**:
  - Level 1 = $stress_{ti}$ – $\mathbf{stressTime0_i}$ → longitudinal effect
    - L1 represents *change from baseline*, not deviation from own mean
  - Level 2 = $\mathbf{stressTime0_i}$ – C → cross-sectional effect
    - L2 represents effect of *baseline level*, not effect of mean level averaged over time

Baseline Centering: Caveats

- In using baseline centering instead of person-mean-centering, a complete separation of the BP and WP variance in the time-varying predictor is not obtained:
  - If the time-varying predictor shows change, you are not fitting a model for that change—no separation of true change from error
  - The level-1 predictor for "WP change in X" is both individual differences in change (U_{1i}) and residual deviations from change (e_{ti}), which should each really have their own relationship to the outcome
  - Therefore, there may be systematic BP differences with regard to the individual slope still contained in the WP change in X predictor (which may be related to BP differences in level at time 0)

- A better option is to use a multivariate model instead, in which a model for change X is fitted for both X and Y
  - Can examine relationships between intercepts, slopes, and residuals as separate model parameters
  - Can be done in MLM programs, but more flexibility in SEM programs

Multivariate Models via M-SEM

- Person-MC (or baseline centering) is the poor man's version of a model-based decomposition of BP and WP variance, which is necessary when X is treated as a predictor in MLM programs
- Through Multilevel Structural Equation Modeling (M-SEM), it is possible to fit a model for X along with the model for Y
  - It's called SEM because random effects = latent variables, but there is no latent variable measurement model as in traditional uses of SEM
  - Person mean = random intercept variance, WP deviation = residual variance, but can also include random slopes for change over time in X
  - Can directly assess multilevel mediation through simultaneous analysis
  - Some evidence that level-2 effects are less biased (because person mean is not perfectly reliable), but more imprecise (more parameters to estimate)
- What could go wrong? No REML! Good luck fitting interactions!
  - Those involving level-2 effects are modeled as latent variable interactions
  - This requires numeric integration, a very computationally intense way of getting parameter estimates in ML, which may not be possible in all data