The multilevel vector autoregressive (VAR) model: gaining insight in bidirectional temporal associations

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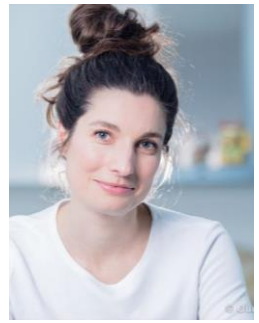

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Two time points
Risk: explaining between-person differences

Anxiety and Depression as Bidirectional Risk Factors for One Another:
A Meta-Analysis of Longitudinal Studies

Nicholas C. Jacobson and Michelle G. Newman
The Pennsylvania State University

- Do people with higher levels of anxiety than others have a higher risk of depressive symptoms than others in the future?

- Depression (baseline) → Anxiety (follow-up)
- Anxiety(baseline) → Depression (follow-up)

Within-person versus between-person

Between-person question (risk):

Do patients who have higher levels of anxiety **than others** have higher levels levels of depressive symptoms **than others** at a next moment in time?

Within-person question (mechanism):

Do patients who have higher levels of anxiety **than usual** do have higher levels of depressive symptoms at a next moment in time **than usual**?

Intensive longitudinal data

Monthly, weekly, daily, hourly data

Do within-person changes in anxiety predict within-person changes in depression at the next moment in time?

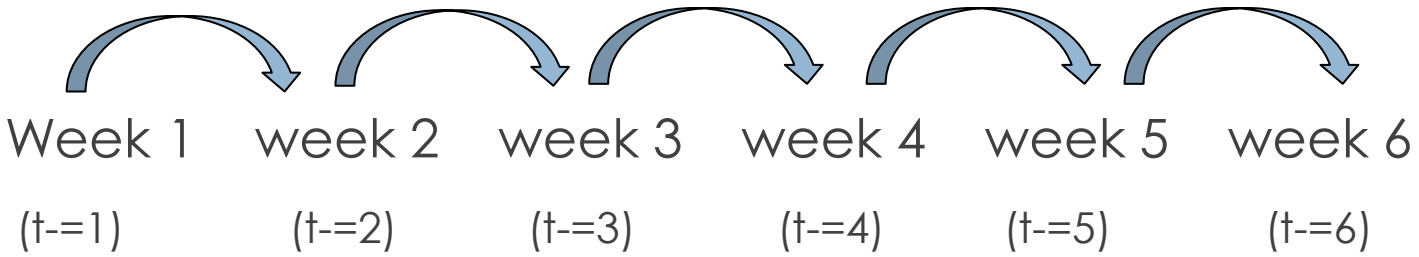
- Multilevel Vector Autoregressive (VAR) model

Temporal precedence: Achilles heel of mechanisms of change

Lagged (temporal) association:

$Depression_{(t-1)} \longrightarrow Anxiety_{(t)}$

$Anxiety_{(t-1)} \longrightarrow Depression_{(t)}$



Vector Autoregressive model (VAR)

Autoregression

1 single subject

$$Y_t = \beta_0 + \beta_1 Y_{t-n} + \beta_2 X_{t-n} + \varepsilon_t$$

$$X_t = \beta_0 + \beta_1 X_{t-n} + \beta_2 Y_{t-n} + \varepsilon_t$$

Predictor of interest

Depression(t) = Depression (t-1) + Anxiety (t-1) + error

Anxiety(t) = Depression (t-1) + Anxiety (t-1) + error

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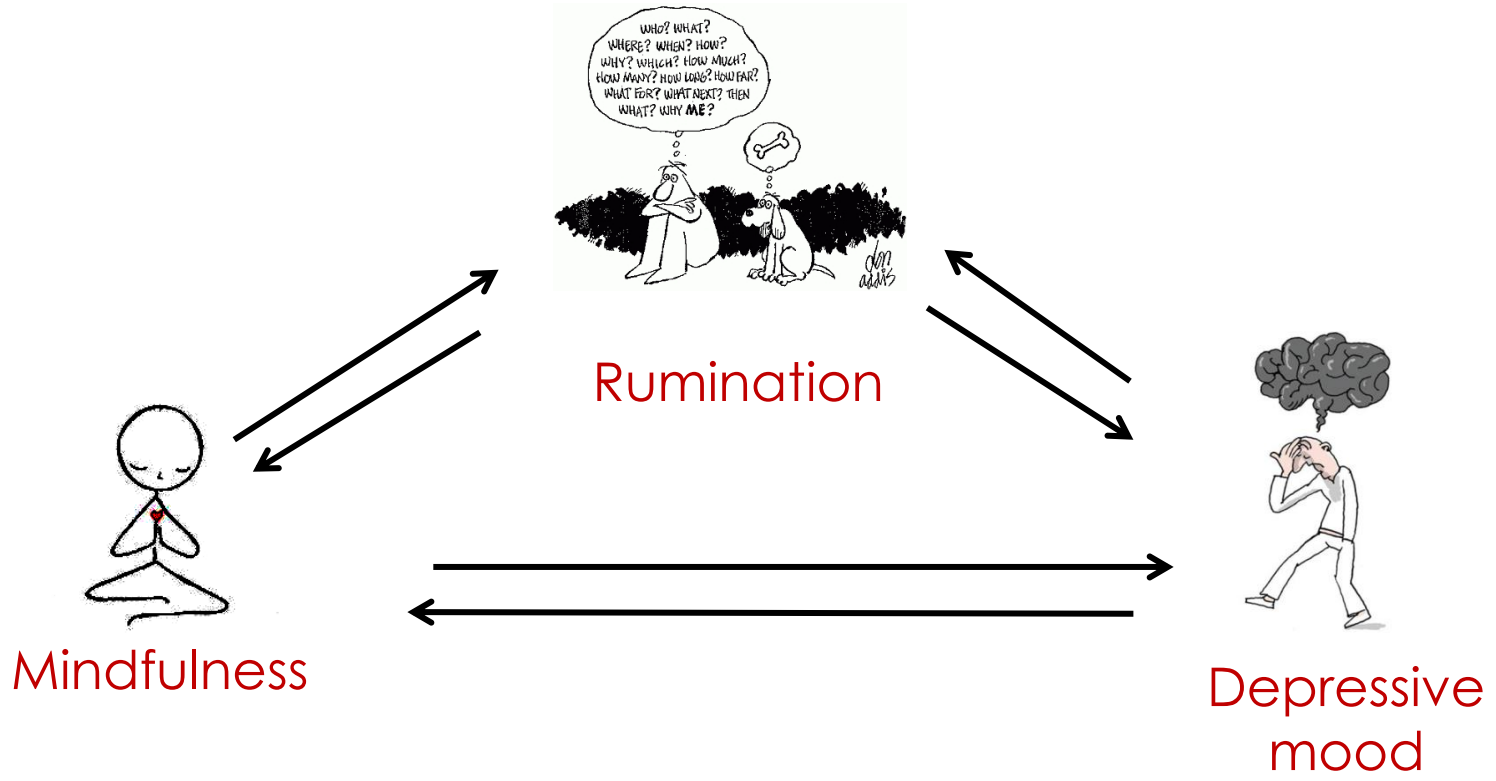
Sims (1982); Lütkepohl (2006); Brandt & Williams (2007)

Do within-person fluctuations in mindfulness and rumination predict following within-person fluctuations in depressive mood, rather than the other way around?



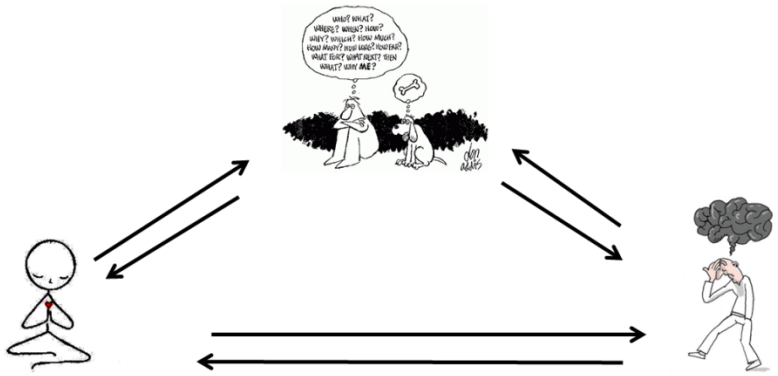
Snippe, Bos, et al., 2015, *Mindfulness*

VAR model

N=6 / 56-77 daily self-reports per participant

Endogeneous part of model:

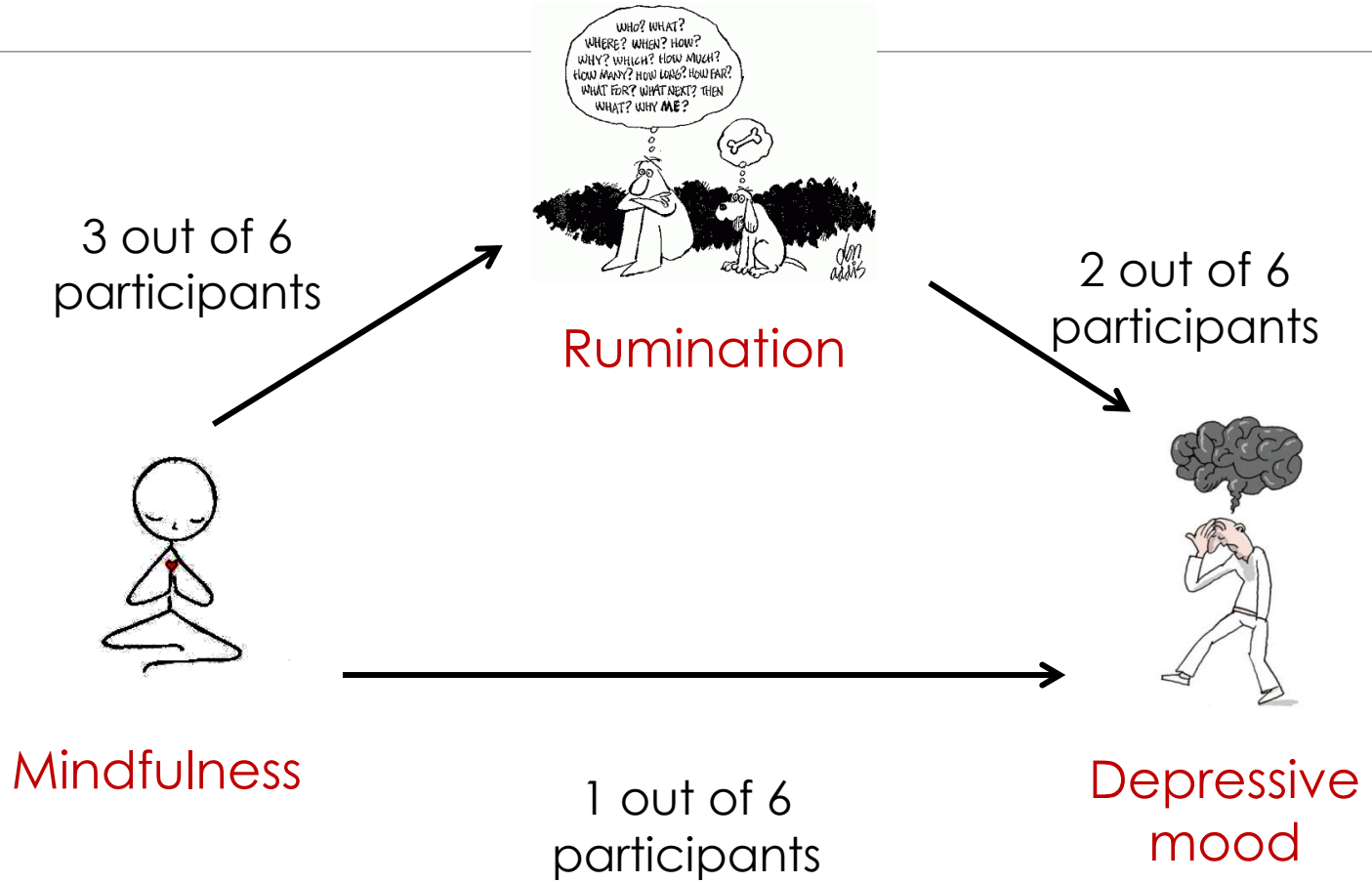
$$\mathrm{Depr}_t = \mathrm{Depr}_{t-i} + \mathrm{Rumi}_{t-i} + \mathrm{Mind}_{t-i}$$
$$\mathrm{Mind}_t = \mathrm{Mind}_{t-i} + \mathrm{Rumi}_{t-i} + \mathrm{Depr}_{t-i}$$
$$\mathrm{Rumi}_t = \mathrm{Rumi}_{t-i} + \mathrm{Depr}_{t-i} + \mathrm{Mind}_{t-i}$$



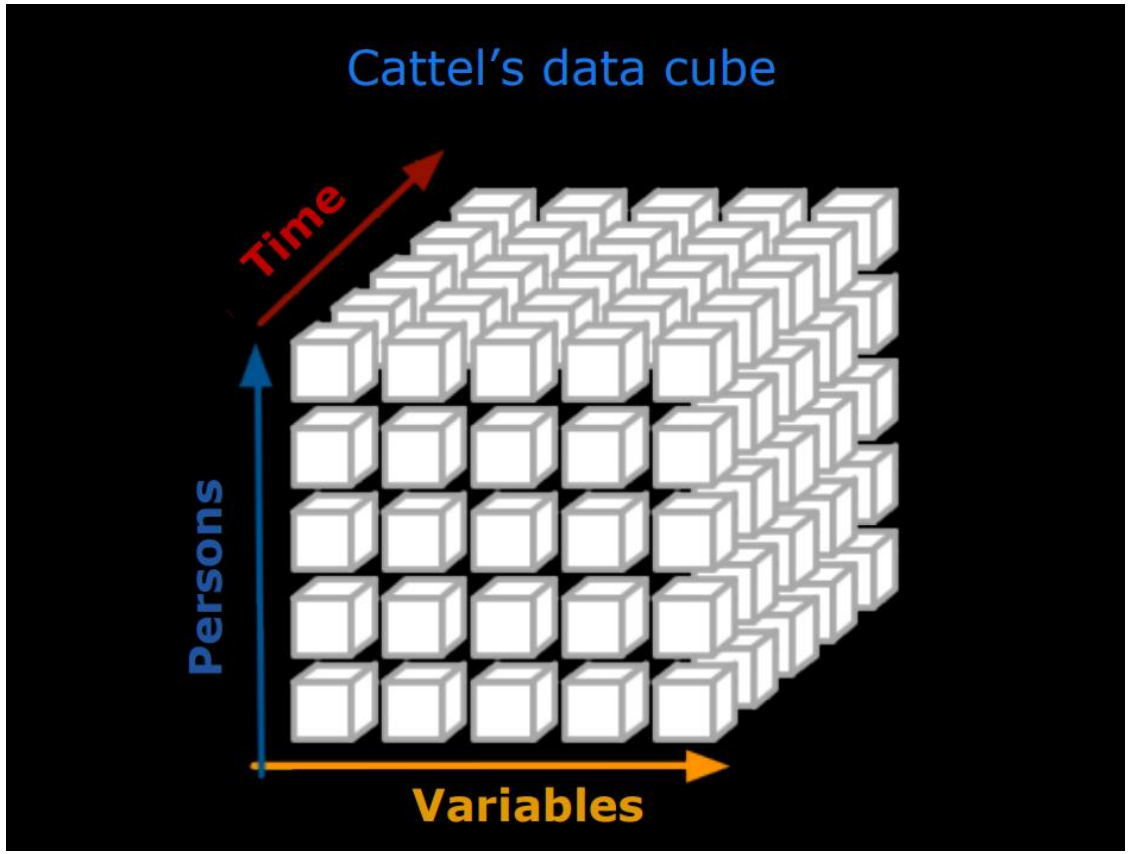
Exogeneous variables

- Time, time^2

No effects in the opposite direction
Few effects in the expected direction



Multilevel analysis



Possibly the technique with the largest number of synonyms

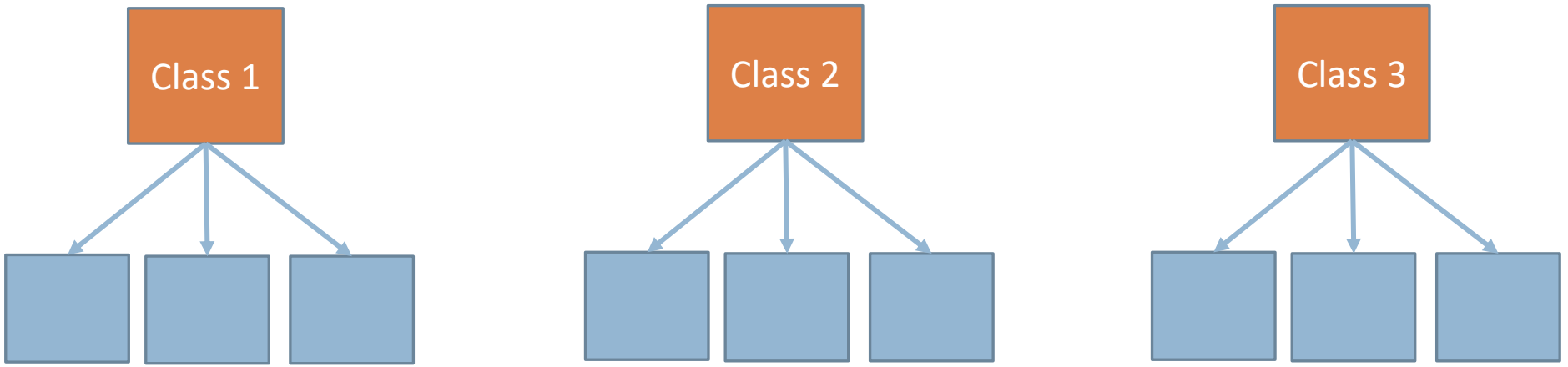
Multilevel

- Hierarchical linear model
- Random coefficient model
- Mixed linear model
- Mixed-effects model
- Mixed model
- Random parameter model
- Nested data model

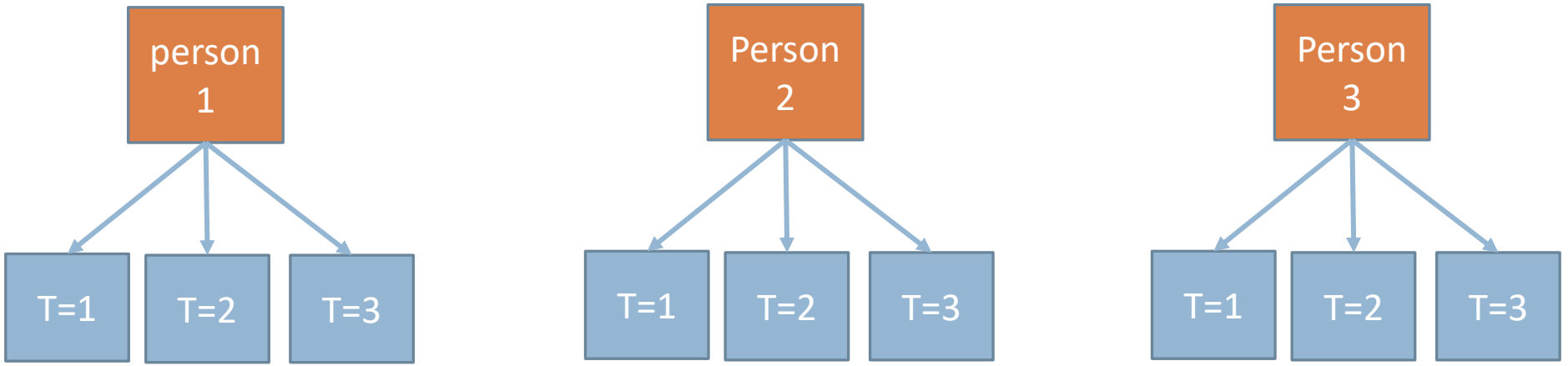
Similar to multilevel VAR

- time-series panel analysis
- dynamic SEM
- Hybrid random effect model
- random intercept cross-lagged panel models

Students within classes

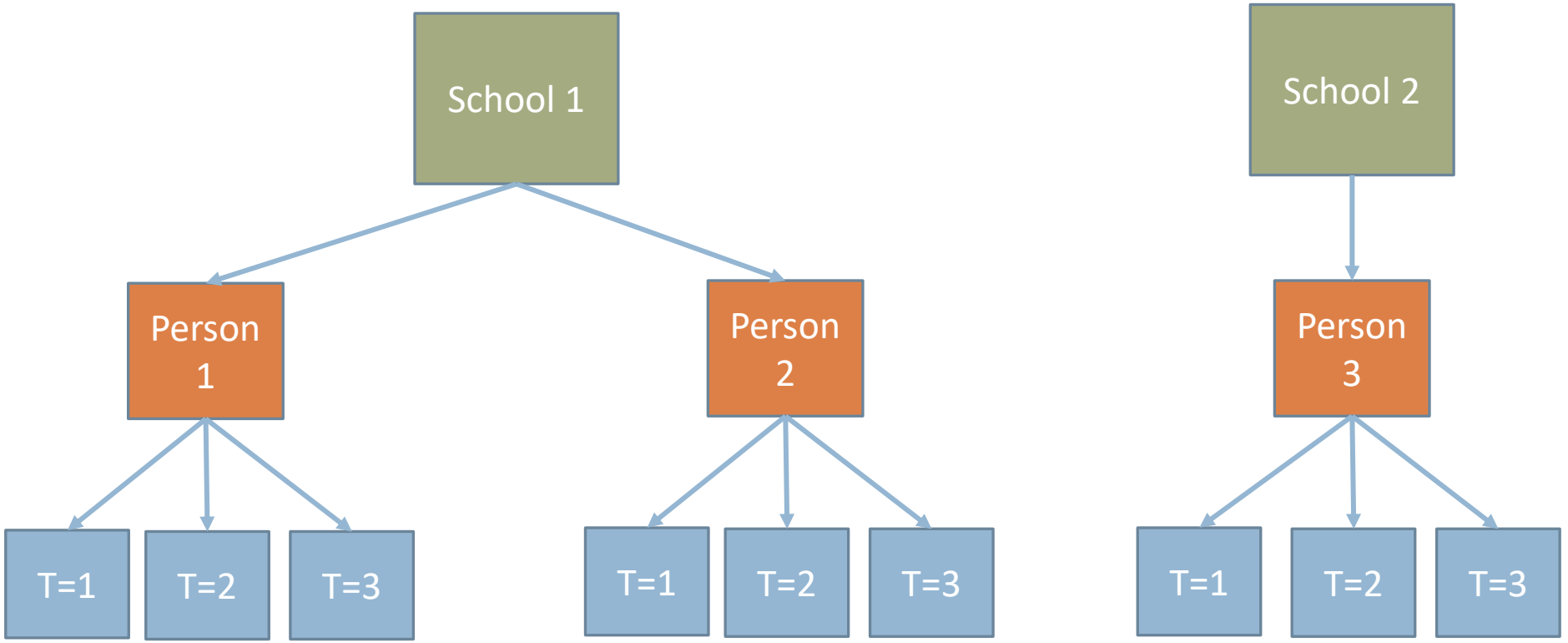


Observations within persons



- Measurements are NESTED within subjects:
- Dependency:measurements of one subject are more alike than measurements of other subjects

More levels are possible



The multilevel VAR model

Level 1 equation: $Y_{it} = \beta_{0i} + \beta_{1i}Y_{it-1} + \beta_{2i}X_{it-1} + \varepsilon_{it}$ ← You can add time-variant / time-invariant predictors /interactions

Level 2 equations:

$\beta_{0i} = \gamma_{00} + u_{0i}$ ← mean intercept + Individual variation around mean intercept (random intercept)

$\beta_{1i} = \gamma_{10} + u_{1i}$ ← mean slope t + Individual variation around mean slope (random slope)

Rovine & Walls (2006). Multilevel autoregressive modeling of interindividual differences in the stability of a process. In T. A. Walls & J. L. Schafer (Eds.), *Models for intensive longitudinal data*

Example: association between negative affect and cortisol

Dependent variable: LnCortisol

Fixed Effects

	Estimate	Sig.
Intercept	1.920	<.001
NegativeAffect(ln)	0.12	.002

Average association between NA and cortisol

Random Effects

		Estimate	Sig.
Intercept	Variance	0.497	<.001
NegativeAffect(ln)	Variance	0.051	.004

Between-person variation in the association between NA and cortisol

Covariance structure in multilevel models

In longitudinal data, errors are correlated

Can specify covariance structure of the random effects AND of the residuals

Poorly specified covariance structure → biased standard errors of fixed effects

Covariance structures

AR(1)

$$\sigma^2\begin{bmatrix} 1 & \rho & \rho^2 & \rho^3 \\ \rho & 1 & \rho & \rho^2 \\ \rho^2 & \rho & 1 & \rho \\ \rho^3 & \rho^2 & \rho & 1 \end{bmatrix}$$

Compound Symmetry

$$\sigma^2\begin{bmatrix} 1 & \rho & \rho & \rho \\ \rho & 1 & \rho & \rho \\ \rho & \rho & 1 & \rho \\ \rho & \rho & \rho & 1 \end{bmatrix}$$

Identity

$$\sigma^2\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Toeplitz

$$\sigma^2\begin{bmatrix} 1 & \rho_1 & \rho_2 & \rho_3 \\ \rho_1 & 1 & \rho_1 & \rho_2 \\ \rho_2 & \rho_1 & 1 & \rho_1 \\ \rho_3 & \rho_2 & \rho_1 & 1 \end{bmatrix}$$

Unstructured

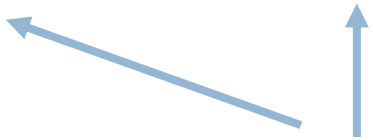
$$\begin{bmatrix} \sigma_1^2 & \sigma_{21} & \sigma_{31} & \sigma_{41} \\ \sigma_{21} & \sigma_2^2 & \sigma_{32} & \sigma_{42} \\ \sigma_{31} & \sigma_{32} & \sigma_3^2 & \sigma_{43} \\ \sigma_{41} & \sigma_{42} & \sigma_{43} & \sigma_4^2 \end{bmatrix}$$

Variance Component

$$\begin{bmatrix} \sigma_1^2 & 0 & 0 & 0 \\ 0 & \sigma_1^2 & 0 & 0 \\ 0 & 0 & \sigma_1^2 & 0 \\ 0 & 0 & 0 & \sigma_1^2 \end{bmatrix}$$

Fixed effects are **a mix** of between- and within-person effects!

$$Anxiety_{it} = \beta_{0i} + \beta_{1j}Anxiety_{i(t-1)} + \beta_{2j}Depression_{i(t-1)} + \varepsilon_{it}$$



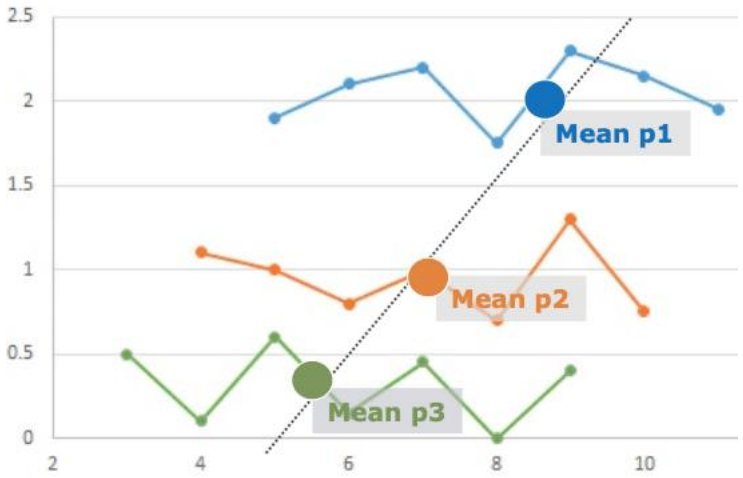
These effects are not (necessarily) within-person

Between person effects: association between **average** levels of anxiety and depression

Within person effects: association between within-person **fluctuations** in anxiety and depression

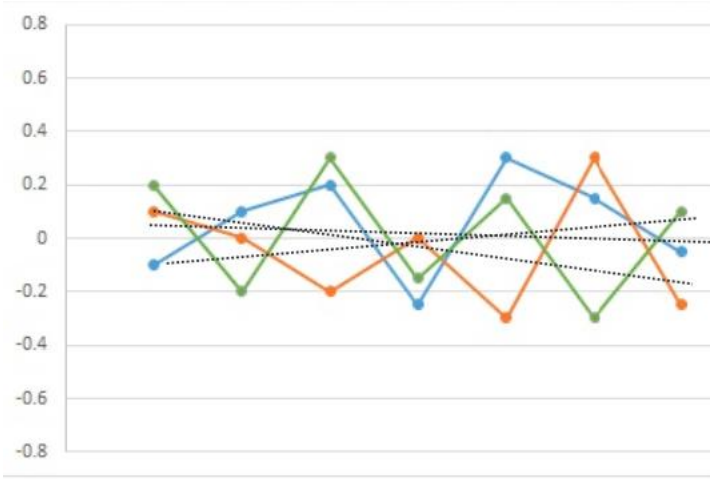
Curran PJ, Bauer DJ (2011). The disaggregation of within-person and between-person effects in longitudinal models of change. *Annu Rev Psychol*, 62, 583-619

Person-mean centering of time-varying data



Raw data

Person-mean centered data
Deviation from person mean



Deviation from person mean: each observation − person mean

$$X_{it} - X_i$$

Disaggregated between- and within-person effects

Dependent variable: Positive affect

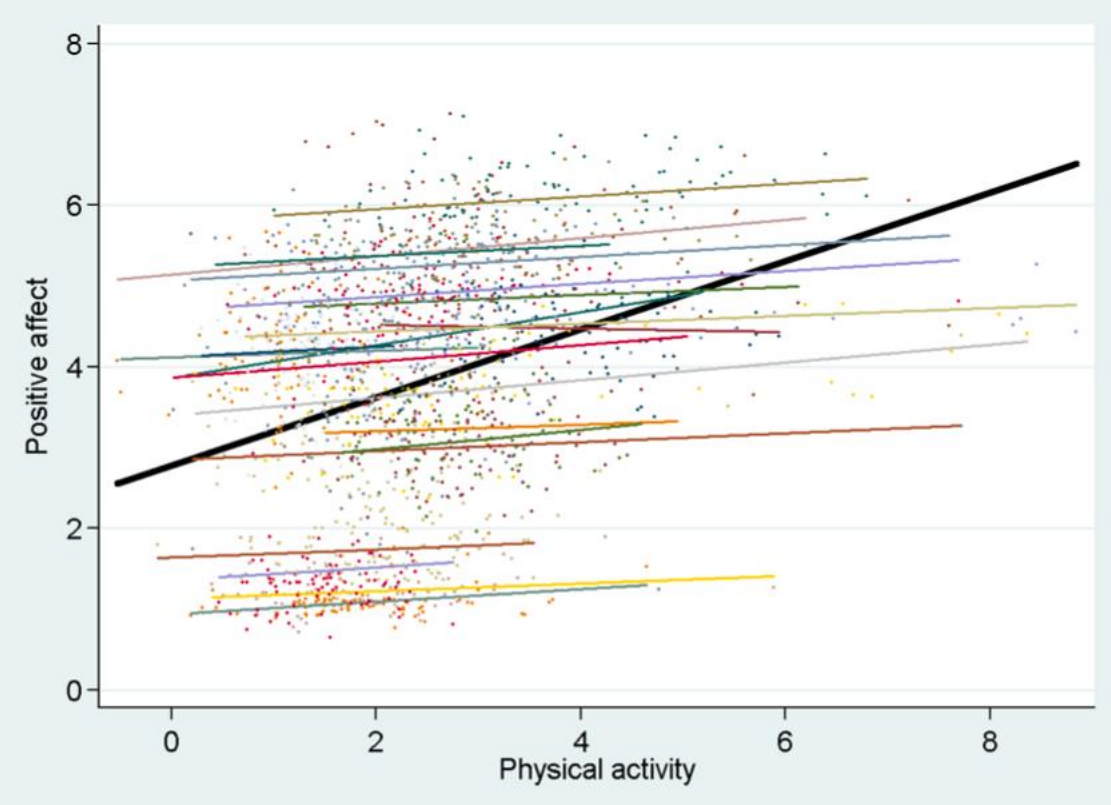
Fixed Effects

	Estimate	Sig.
Physical activity (person-mean centered)	0.078	<.001
Physical activity (person means)	1.043	.006

within

between

Stronger between-person than within-person effects



JAN. 18, 2017

Neurotics Get an Extra Benefit From Being Extra Nice

By Drake Baer

HOEGEKIS.NL – HOW NUTS ARE THE DUTCH?

Experience Sampling Methodolody (ESM)
Ecological Momentary Assessments (EMA)

3 times a day

Momentary positive feelings:
I feel cheerful, content, relaxed, enthusiastic, calm

Prosocial behavior:
Since the last measurement I was able to make a difference to someone

Snippe, Jeronimus, aan het Rot, Bos, de Jonge, Wichers, *Journal of Personality*, 2017

JAN. 18, 2017

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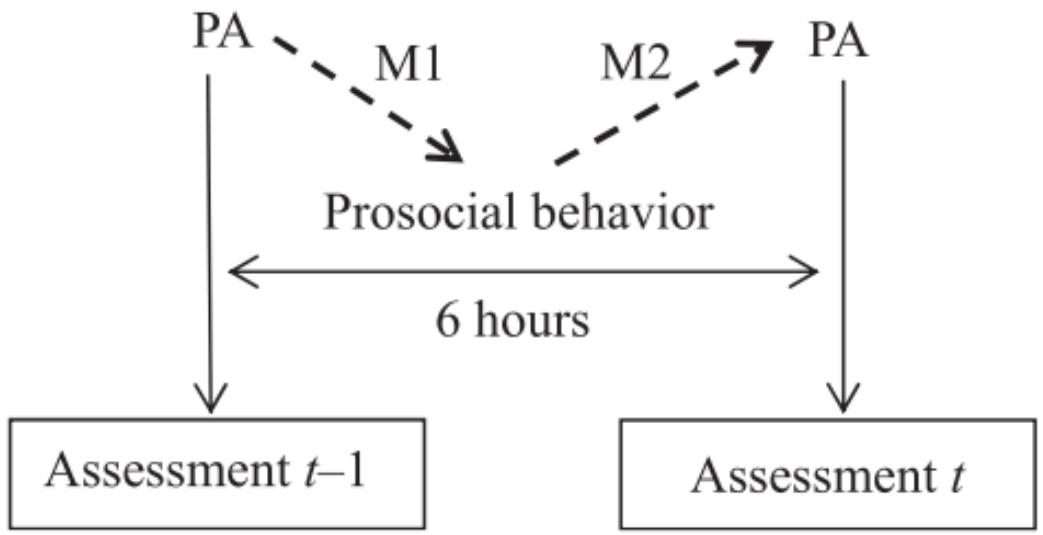


Figure 1 Timing of the assessments. PA = positive affect; M1 = Model 1; M2 = Model 2. The dashed arrows reflect the performed analyses. PA was assessed momentarily and prosocial behavior was assessed retrospectively, covering the previous 6 hours (from $t-1$ to t).

It does not always makes sense to model temporal associations.

Think about the speed of the expected associations

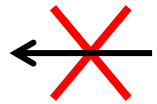
Interaction between time-varying predictor (level 1) and time-invarying predictor (level 2)

$$PA_{it} = \beta_{0i} + \beta_{1j} PA_{i(t-1)} + \beta_{2j} Prosocial_{i(t)} + \beta_{3j} Prosocial_{i(t-1)} * Neuroticismi + \varepsilon_{it}$$

Snippe, Jeronimus, aan het Rot, Bos, de Jonge, Wichers, *Journal of Personality*, 2017

Daily fluctuations in mindfulness predict fluctuations in affect the day after, not the other way around

Mindfulness



Negative Affect
Positive Affect

Snippe, Nyklicek, Schroevers & Bos, *Journal of Counseling Psychology*, 2015

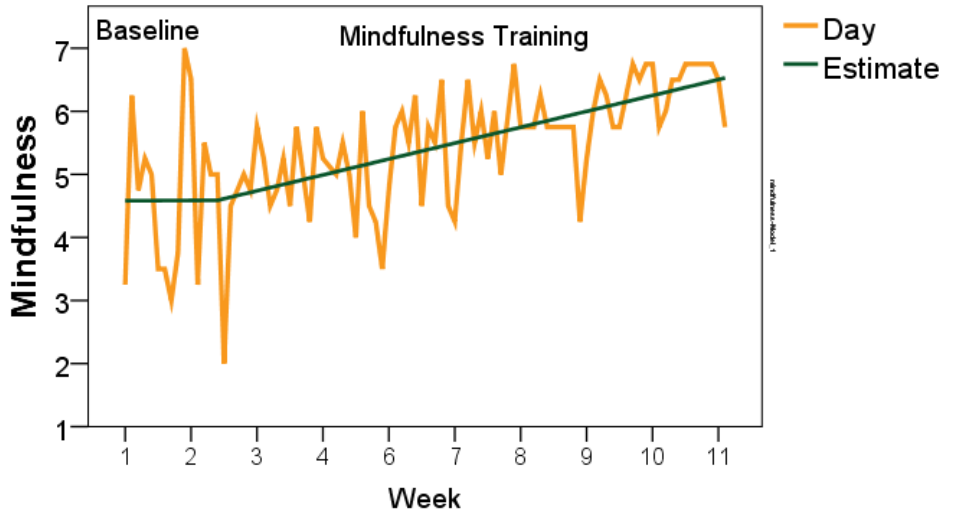
Assumption of stationarity: (non)linear detrending

Trends in data: violates assumption of stationarity

Solution: person-*trend* centering

Problematic:
- No variation left in data if detrended too much
- linear detrending may not fit the data

Solution: collect data during stationary period



Rovine & Walls (2006). Multilevel autoregressive modeling of interindividual differences in the stability of a process.

Assumption of stationarity: associations are stable over time

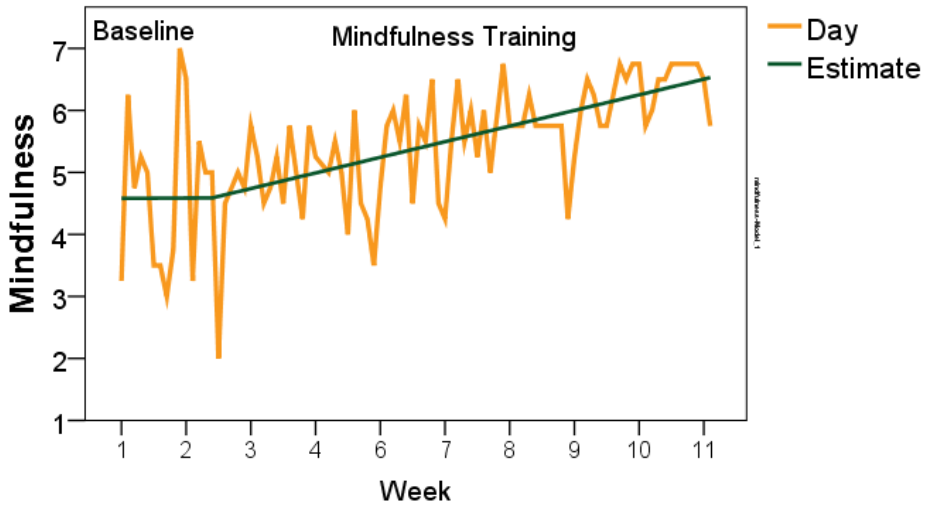
Non-stationary process:

- associations might change over time

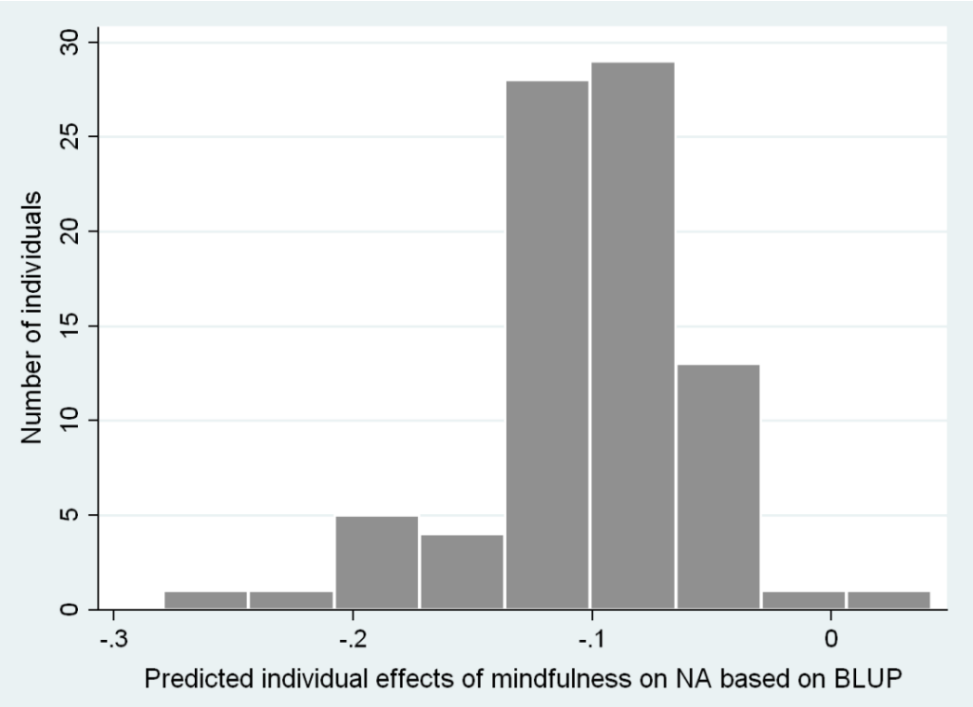
Solution: collect data during stationary period

Solution:

- include interaction between time and fixed effect
- Time-varying Vector Autoregressive models



Heterogeneity
in the association between mindfulness on NA



Variable	NA Model 1
Fixed effects	
Intercept	1.78 (.06)**
Mindfulness$_{t-1}$	−0.10 (.03)**
NA$_{t-1}$	0.14 (.03)**
PA$_{t-1}$	
Random-effect variances	
Level 2 (between person)	
Intercept	0.251 (.040)**
Mindfulness$_{t-1}$	0.012 (.010)*
NA$_{t-1}$	0.018 (.007)*
PA$_{t-1}$	
Level 1 (within person)	
Residual	0.173 (.005)**

Best Linear Unbiased Predictions

Using random effect variances

Limitations multilevel approach

- Random effects: no real prediction of individual effects.
- Random effects: assumption normal distribution
- Average within-person association might be non-existent
- No individual covariance structure and error variances

Limitations multilevel approach

- Average within-person association might be non-existent
- Random effects: no real prediction of individual effects.
- Random effects: assumption normal distribution

Alternative
Group iterative multiple model estimation (GIMME)
Gates & Molenaar (2012)

Associations are estimated for each person separately
Group-structures in these individual associations are estimated

Limitations multilevel VAR

Only discrete time intervals are modeled
Effects may be present at t-1, t-2, t-3 etc
Time-interval dependency

Limitations multilevel VAR

Only discrete time intervals are modeled

Effects may be present at t-1, t-2, t-3 etc

Time-interval dependency

Continuous-time models

(e.g. Ryan & Hamaker, 2021)

Lagged regression parameters at any interval should be interpreted as *total* rather than *direct* relationships

Limitations multilevel VAR

Does not model change in the mean

Limitations multilevel VAR

Does not model change in the mean

Trajectories of mean change:
-Multilevel (latent) growth modeling
-Time-varying effect modeling

Temporal order of mean change
-Assess timing of change for each individual using:
- -Change point analyses
- -Cut-off criteria: e.g. sudden gain criteria or persistent reliable improvement
- -See e.g. Snippe, et al., 2021, *Journal of Affective Disorders*

How to model?

R

Nlme (lme)

Lme4 (lmer)

STATA

Xtmixed

Mplus

Time Series Analysis: Dynamic Structural Equation Modeling (DSEM)

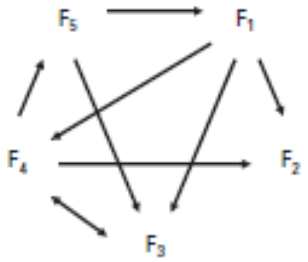
https://www.statmodel.com/TimeSeries.shtml

Advantage multilevel models

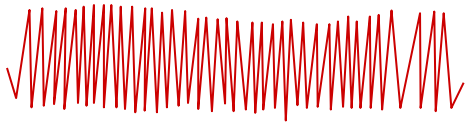
- Flexible, can handle unbalanced data
- You can ”borrow strength” from the group

Advantages multilevel VAR

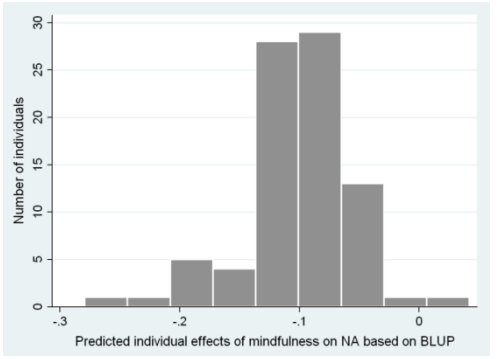
May give insight in:



- Dynamics between variables
- Bidirectional associations



- Temporal associations
- Within-person processes
- Degree of inter individual differences



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Thank you!