Simulating network dynamics and interventions

Gaby Lunansky

Guestlecture Network Analysis

08-12-2022

Overview

- Intro: Why do we estimate networks?
- Simulating interventions in network models
- NodeIdentifyR Algorithm (NIRA)
  - How does the algorithm work?
  - Applying the algorithm to data
- **Empirical Illustration** using a network model of PTSD symptoms
- Reflection

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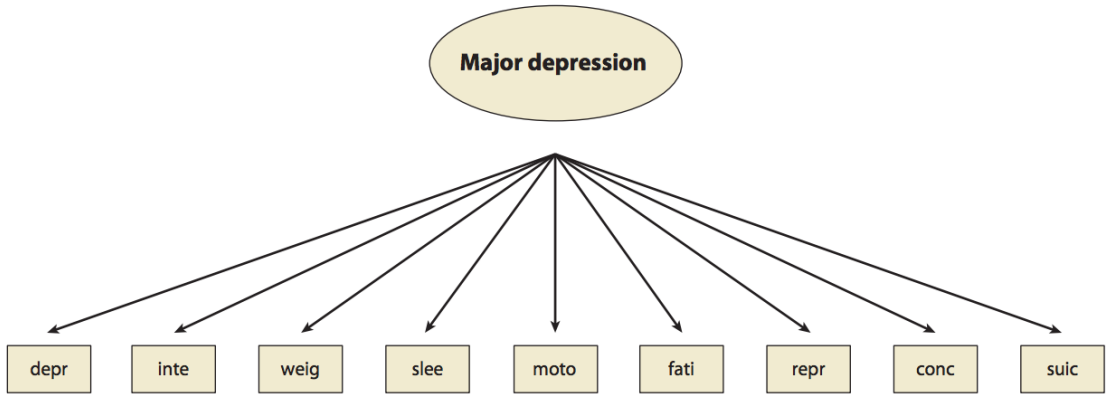
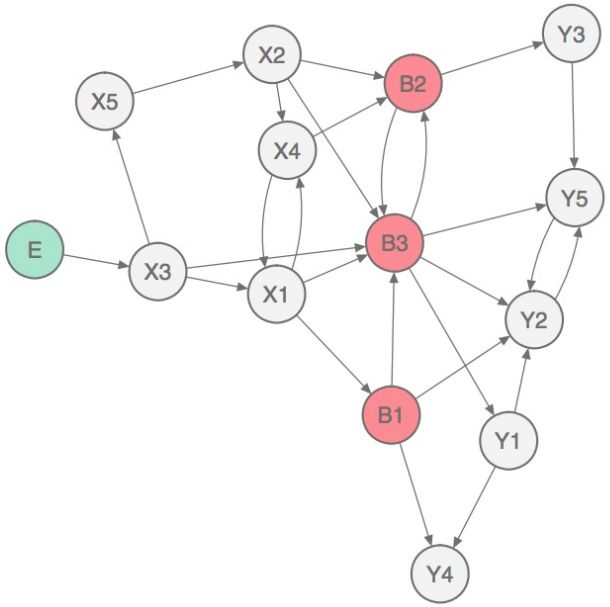
The network approach on psychopathology vs. latent variable models

Latent variable models



(Borsboom & Cramer, 2013, Figure 1)

Network approach



(Fried et al., 2017, Figure 2)

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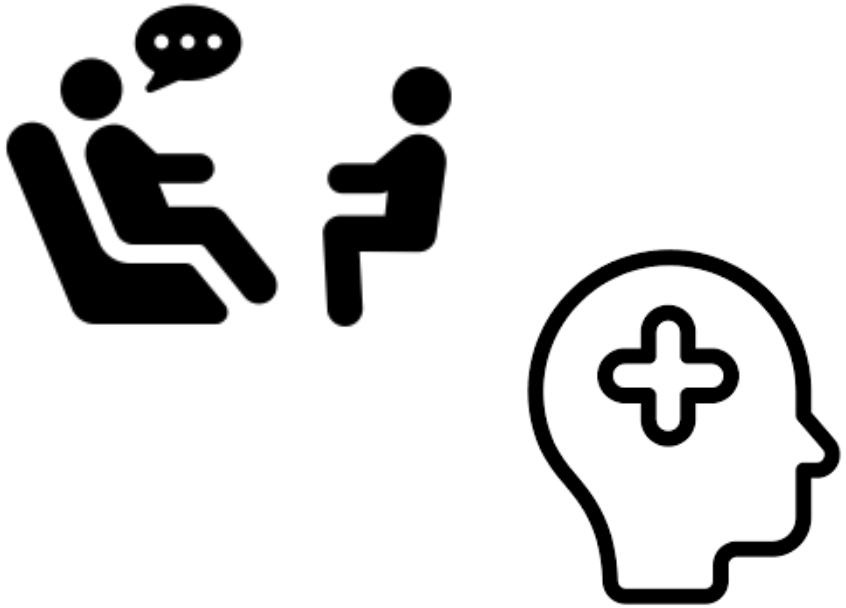
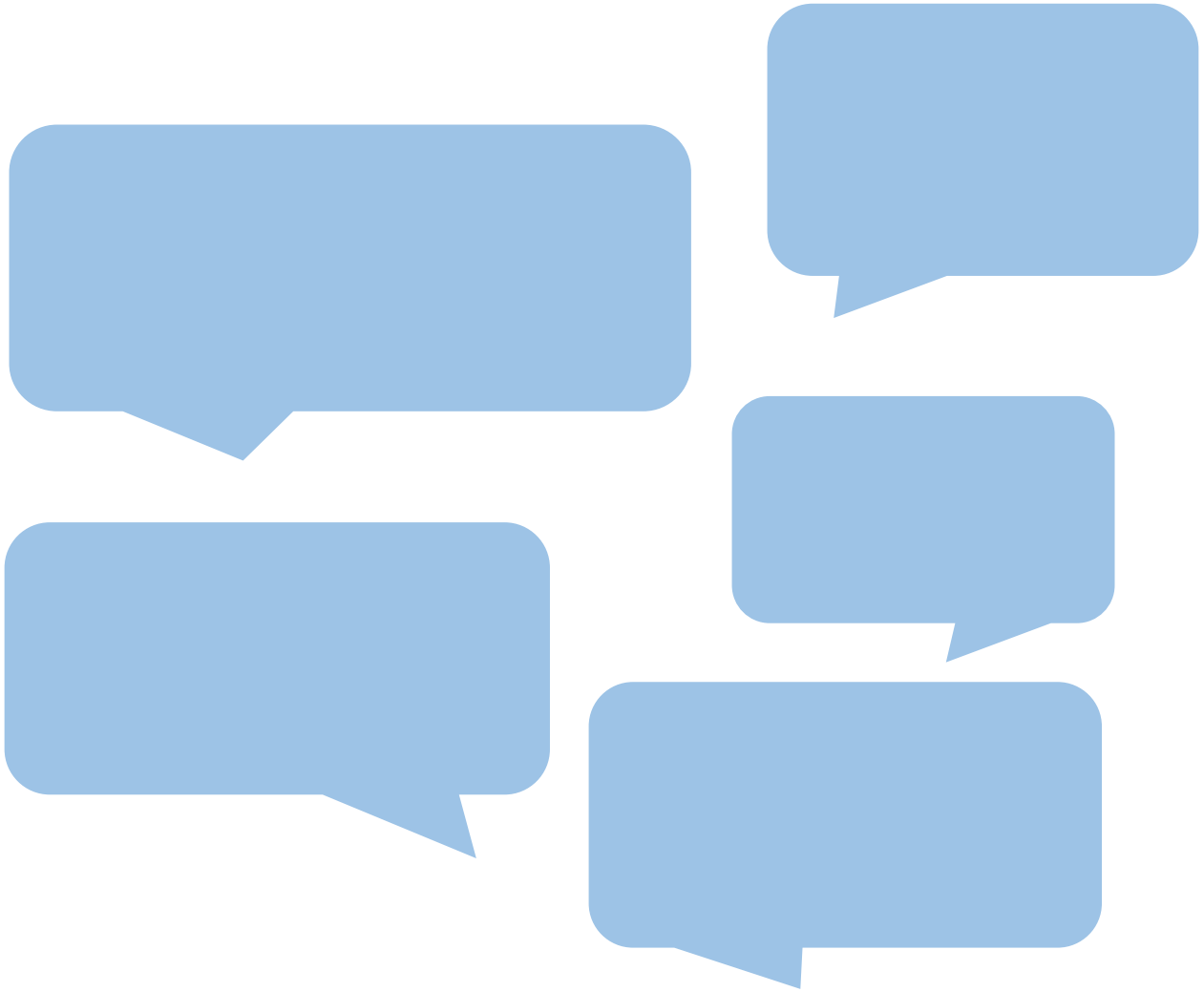
Why are we estimating psychopathology symptom network models?

What does the network approach offer to clinical psychologists/psychiatrist, or clinical psychology researchers?





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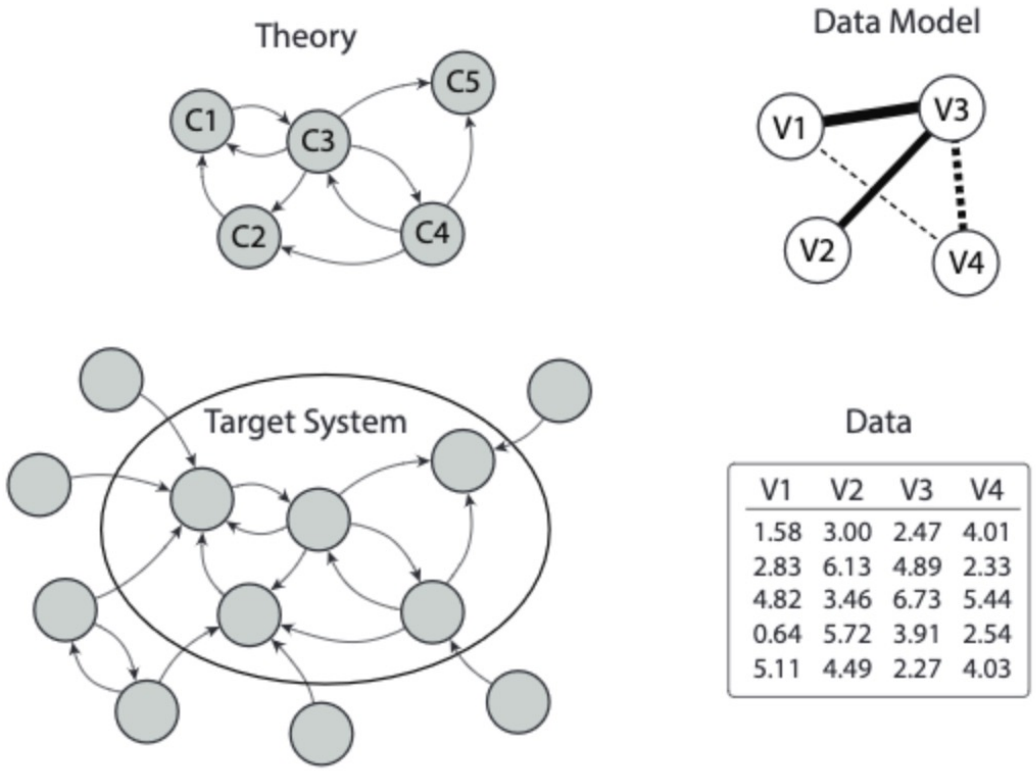
Are these worlds connected?

Figure 1

Key Concepts Theory, Target System, Data, and Data Model



Haslbeck, Ryan, Robinaugh, Waldorp & Borsboom, 2021.

Figure 1.

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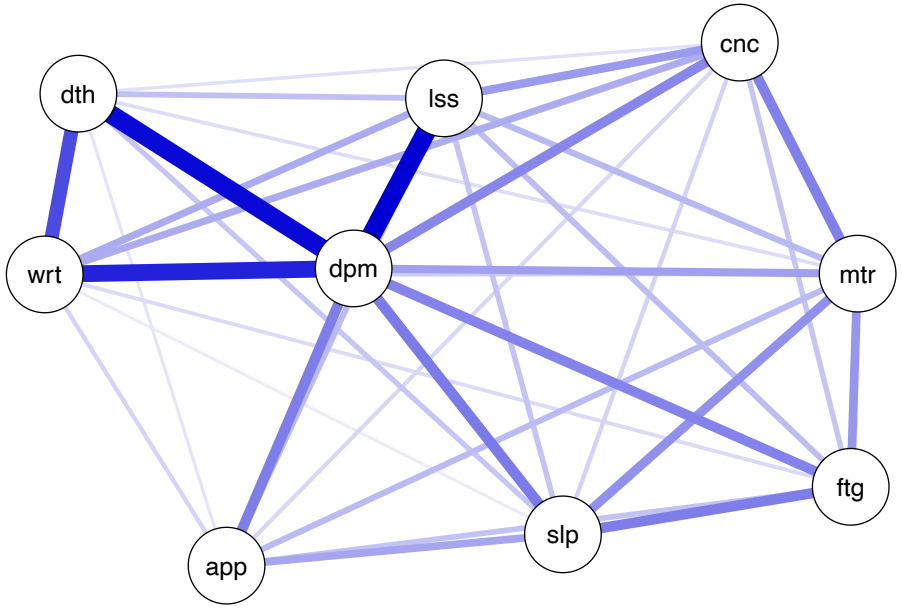
Why are we estimating psychopathology symptom network models?

What can we really say from an estimated network model?



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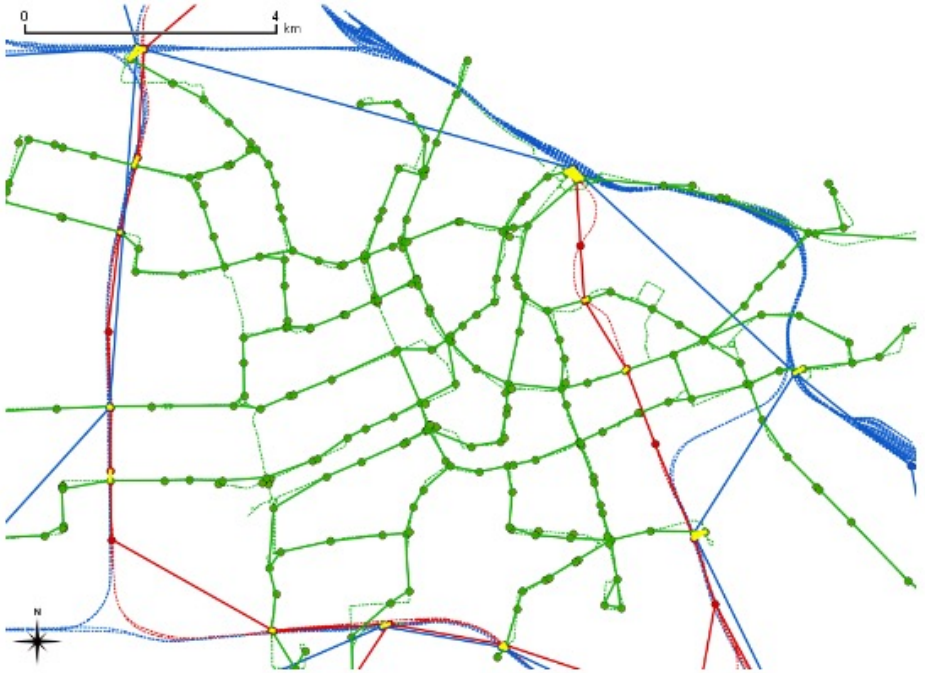
Is there always such a big gap between network theories & network models?



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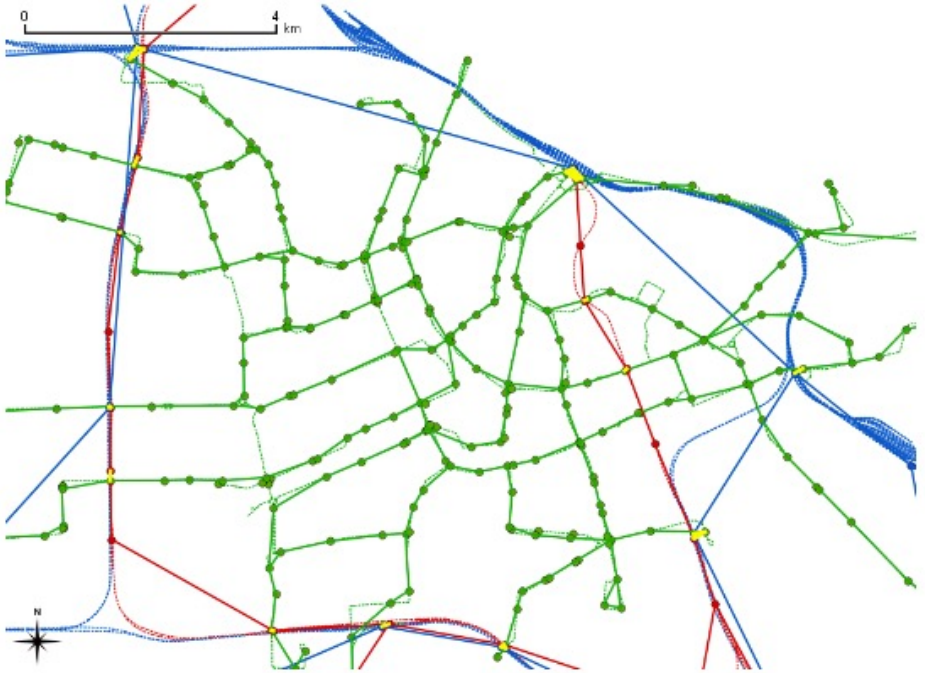
Network structure vs. network dynamics



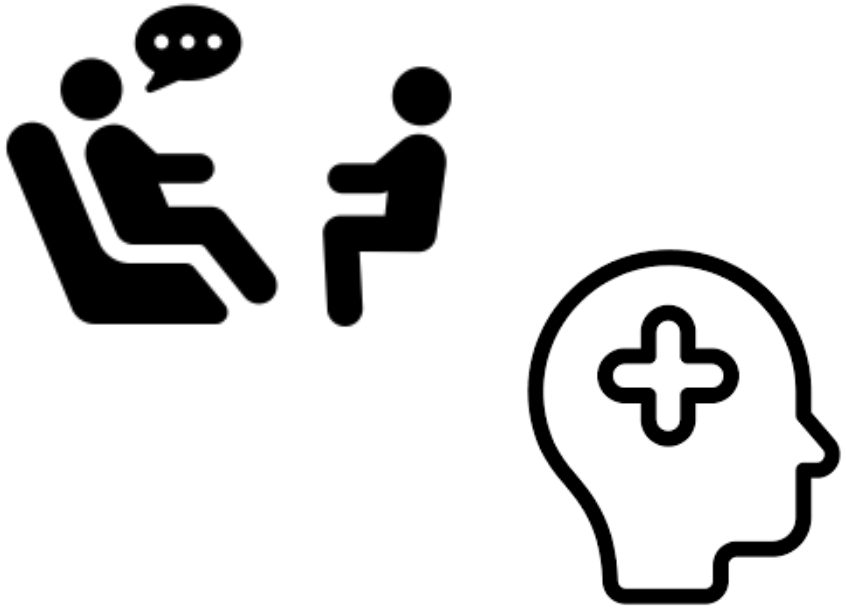
"…topological undirected network where the stations or stops represent nodes in the graph and the mobility infrastructure defines the links."

Gil, J., & Read, S. (2012). Measuring sustainable accessibility potential using the mobility infrastructure's network configuration.

Gaby Lunansky | g.lunansky@uva.nl |

Let’s go back to why we estimate symptom network models

What does the network appraoch offer to clinical psychologists/psychiatrist, or clinical psychology researchers?



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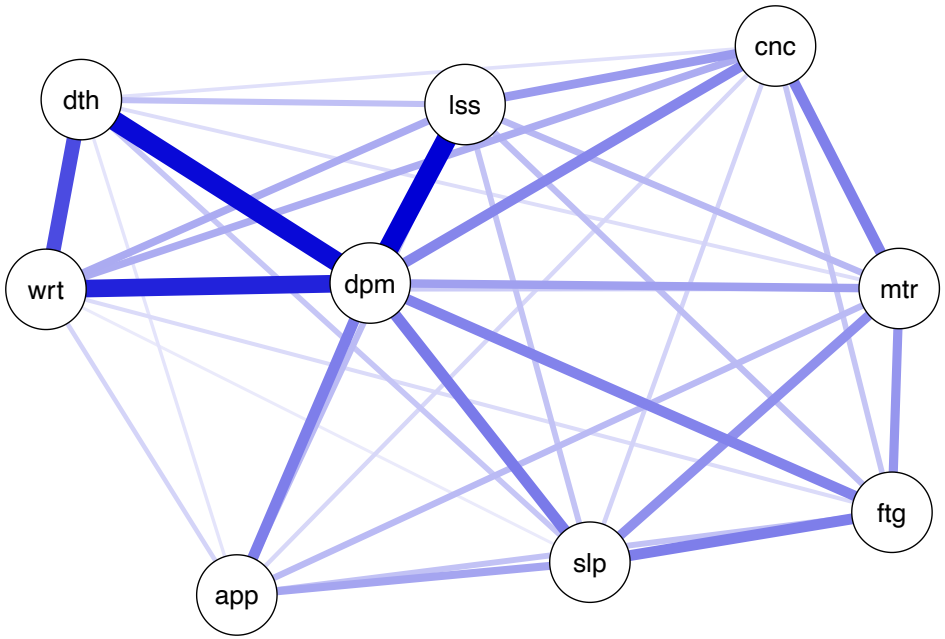
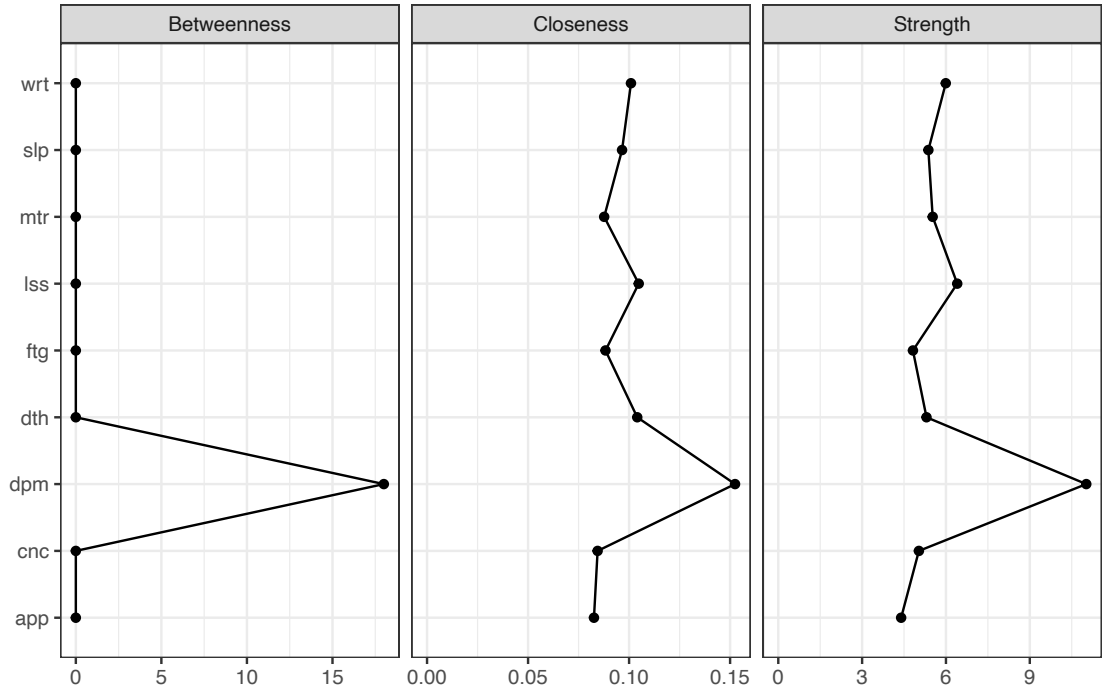
Centrality in psychopathology networks

Centrality metrices are often used to assess the relative importance of symptoms





Gaby Lunansky | g.lunansky@uva.nl |

Critiques

- Can we really infer from the model which symptom is the most urgent to treat in a clinical setting?

- Centrality metrics use the network's *structure* as input, not the *dynamical process* that is assumed to run over the model (Bringmann et al., 2019)

- How do symptoms influence each other's presence?

- A causal process running over the network structure needs to be assumed (Dablander & Hinne, 2019; Haslbeck et al., 2021; Henry et al., 2021).

What do you think?

Should we only use network models as data visualisation techniques? Or should we aim towards using network models as representations of network theory?

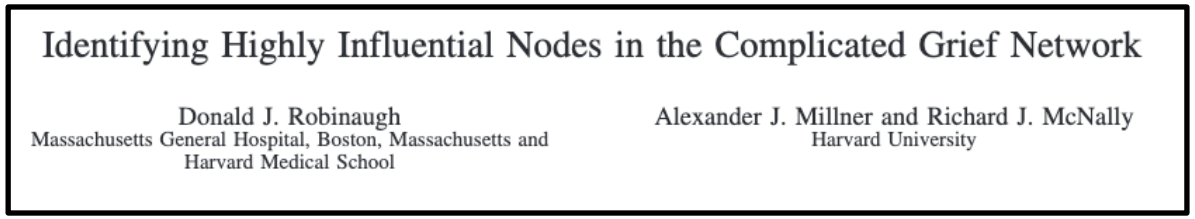
Gaby Lunansky | g.lunansky@uva.nl |

Simulating interventions in network models

Gaby Lunansky | g.lunansky@uva.nl |

Intervening on networks

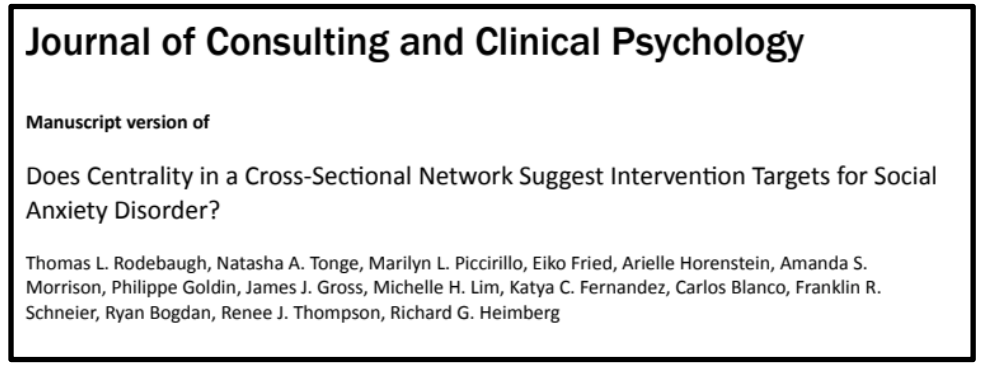
Novel approaches compute the influence of one node on the behavior of the network using symptom-specific simulated interventions



Identifying Highly Influential Nodes in the Complicated Grief Network

Donald J. Robinaugh
Massachusetts General Hospital, Boston, Massachusetts and Harvard Medical School

Alexander J. Millner and Richard J. McNally
Harvard University

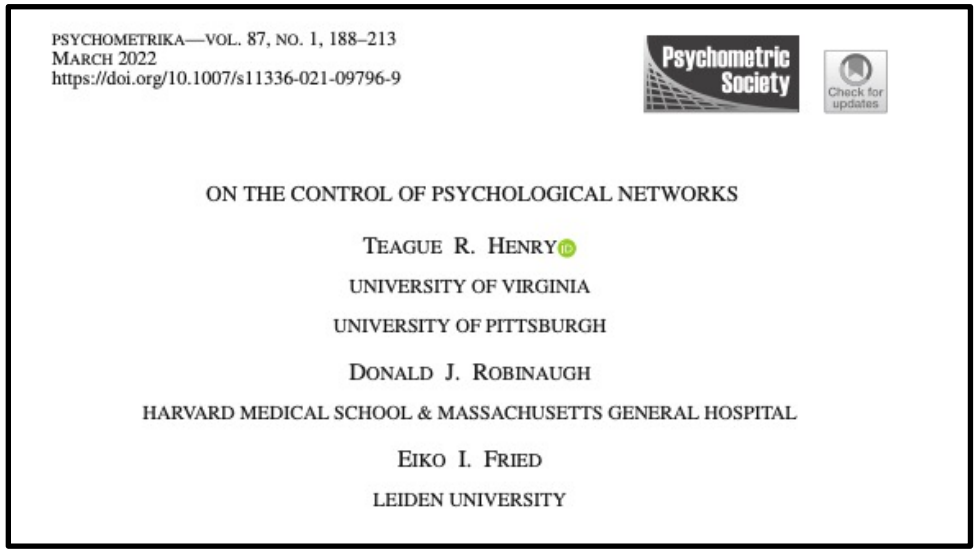


Journal of Consulting and Clinical Psychology

Manuscript version of

Does Centrality in a Cross-Sectional Network Suggest Intervention Targets for Social Anxiety Disorder?

Thomas L. Rodebaugh, Natasha A. Tonge, Marilyn L. Piccirillo, Eiko Fried, Arielle Horenstein, Amanda S. Morrison, Philippe Goldin, James J. Gross, Michelle H. Lim, Katya C. Fernandez, Carlos Blanco, Franklin R. Schneier, Ryan Bogdan, Renee J. Thompson, Richard G. Heimberg



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https://doi.org/10.1007/s11336-021-09796-9

Psychometric Society

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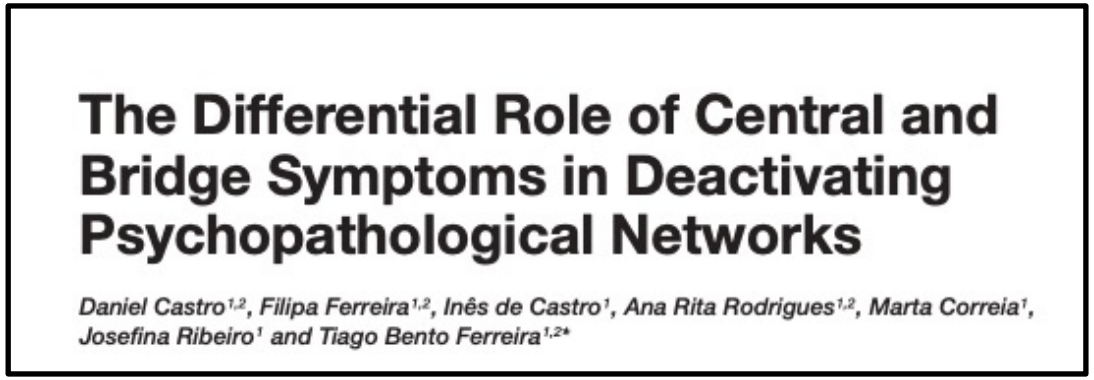
ON THE CONTROL OF PSYCHOLOGICAL NETWORKS

TEAGUE R. HENRY
UNIVERSITY OF VIRGINIA
UNIVERSITY OF PITTSBURGH
DONALD J. ROBINAUGH
HARVARD MEDICAL SCHOOL & MASSACHUSETTS GENERAL HOSPITAL
EIKO I. FRIED
LEIDEN UNIVERSITY



The Differential Role of Central and Bridge Symptoms in Deactivating Psychopathological Networks

Daniel Castro[1,2], Filipa Ferreira[1,2], Inês de Castro[1], Ana Rita Rodrigues[1,2], Marta Correia[1], Josefina Ribeiro[1] and Tiago Bento Ferreira[1,2]*

Gaby Lunansky | g.lunansky@uva.nl |

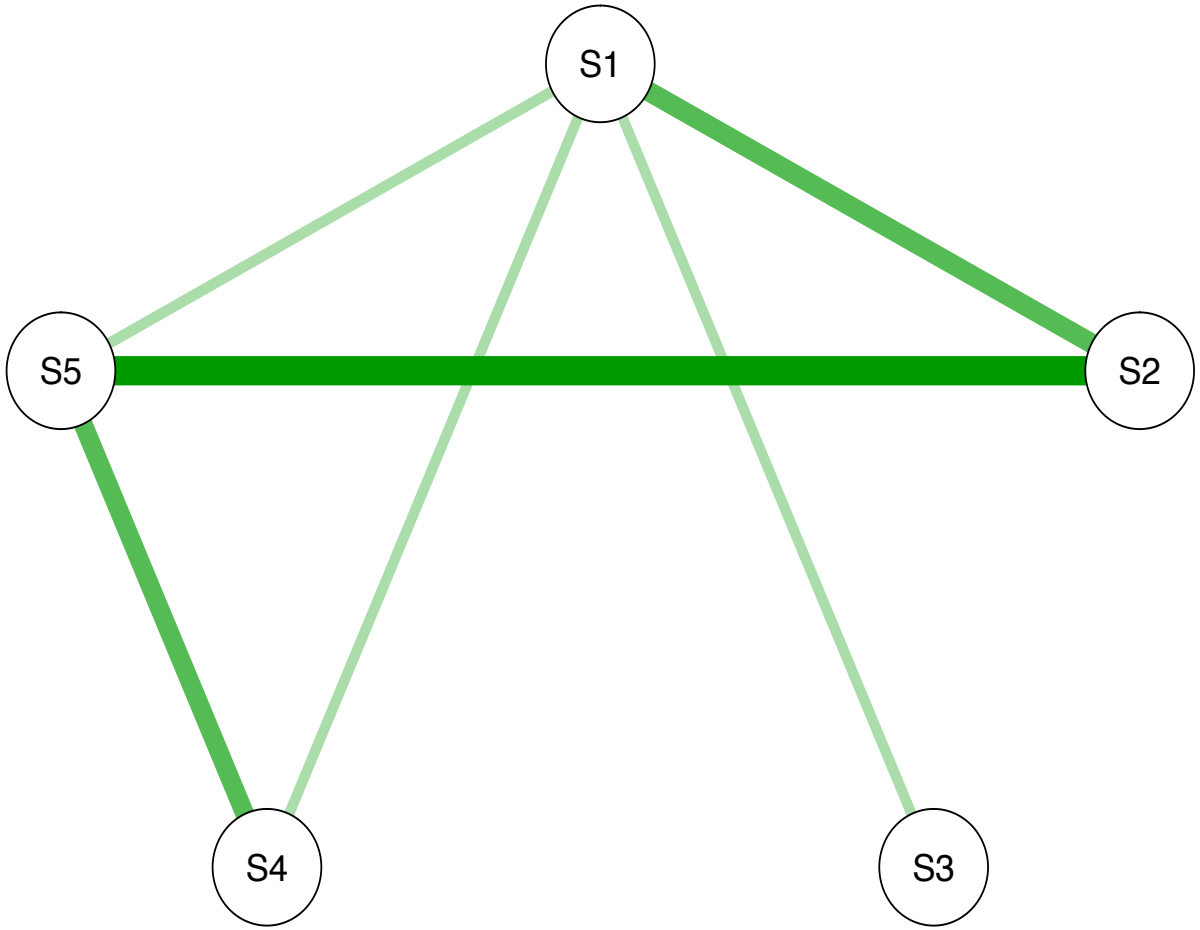
Advantages of using simulations

1) Be explicit about the assumed dynamical process

2) Understand your model

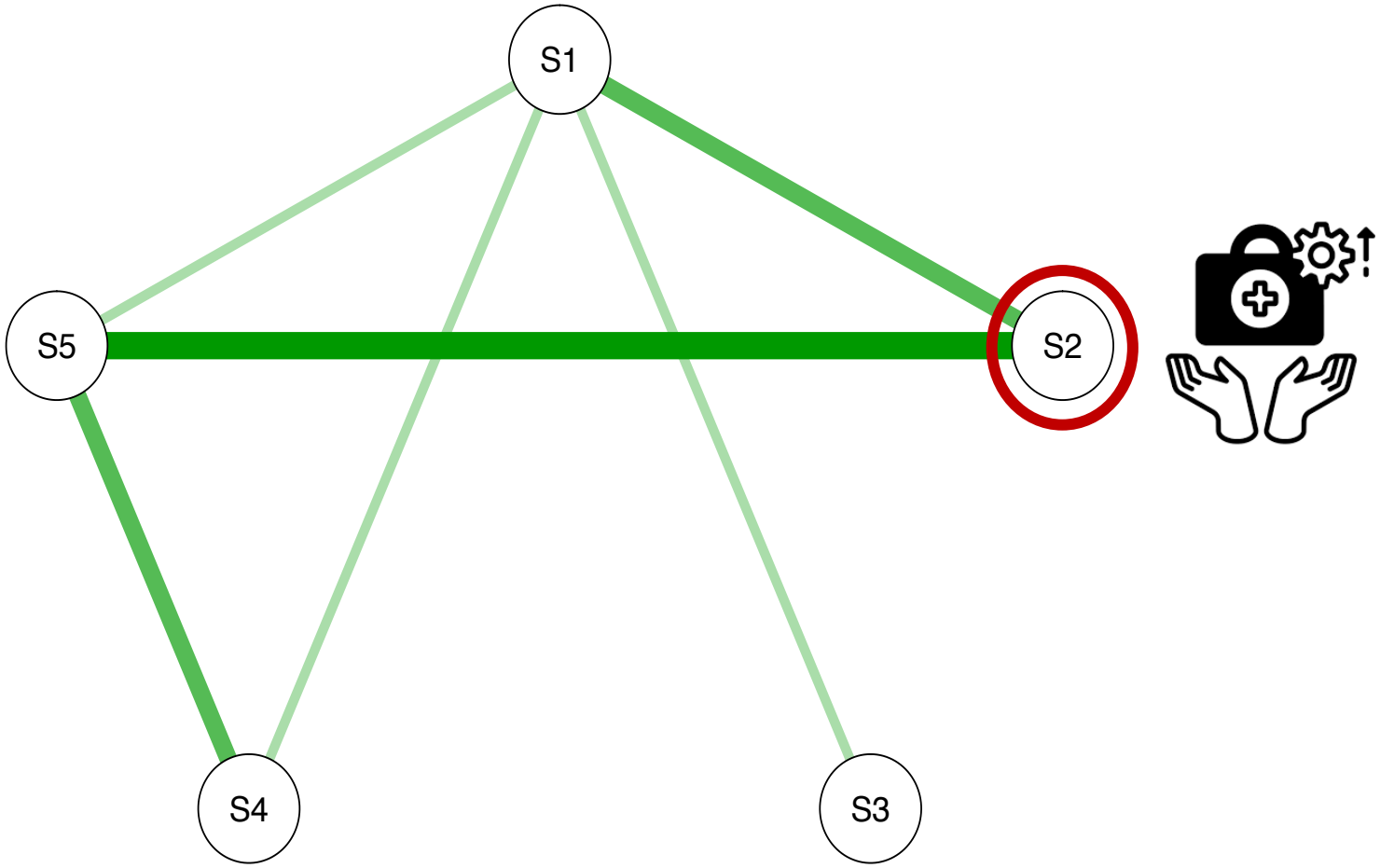
3) Quantify the relative importance of specific parameters

4) Generate clear, specific and testable hypotheses



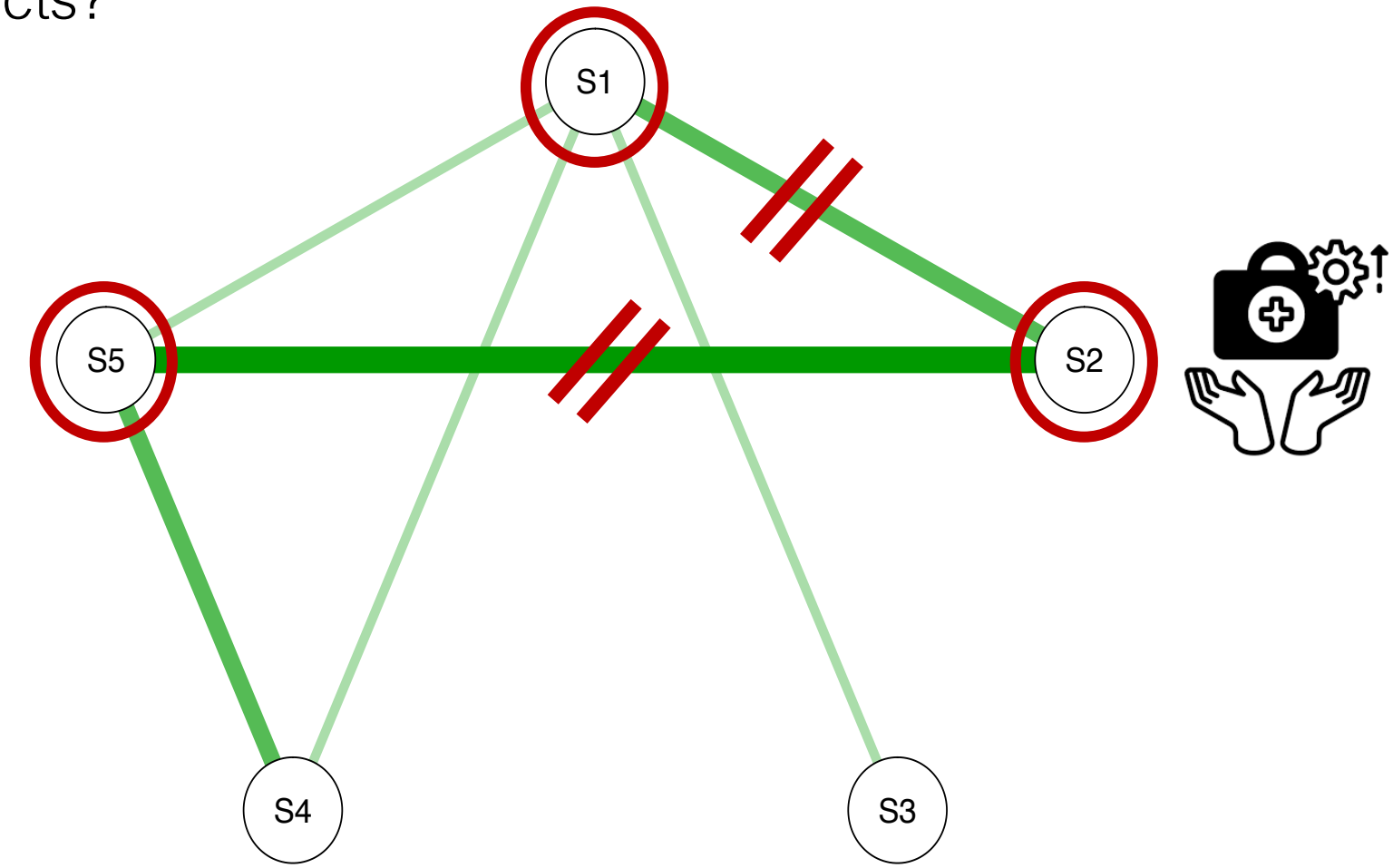
Gaby Lunansky | g.lunansky@uva.nl |

Propelling effects?



Gaby Lunansky | g.lunansky@uva.nl |

Propelling effects?

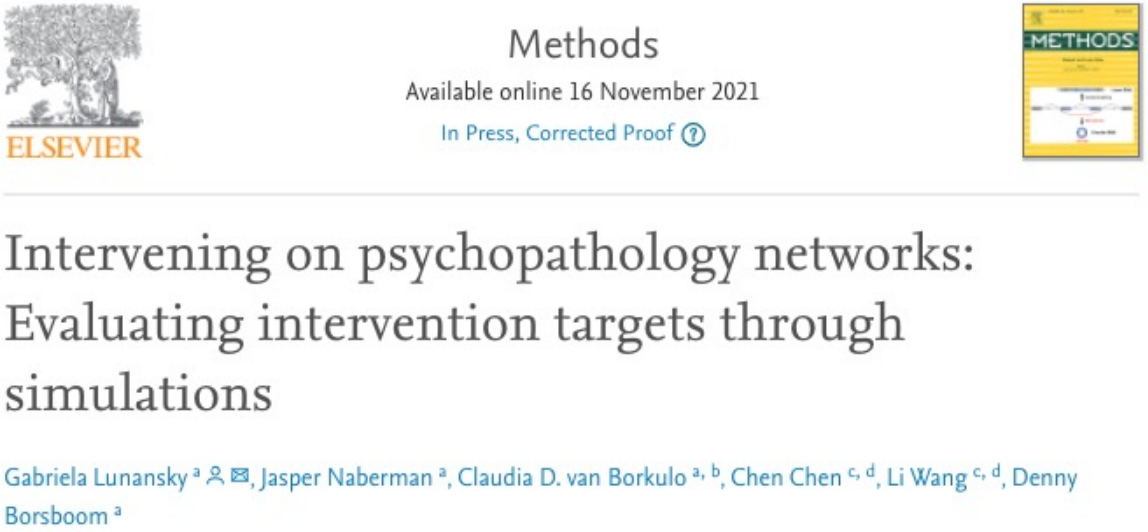


Gaby Lunansky | g.lunansky@uva.nl |

Paper

Open access published in *Methods:*

https://doi.org/10.1016/j.ymeth.2021.11.006



Rest of the team:

Jasper Naberman

Claudia van Borkulo

Chen Chen

Li Wang

Denny Borsboom

Gabriela Lunansky | g.lunansky@uva.nl | University of Amsterdam

Our proposal

In our interventions, we alter the *probability that symptoms will activate* (node parameter) instead of altering their *absence/presence* (node state)

Gabriela Lunansky | g.lunansky@uva.nl | University of Amsterdam

Method is implemented in R package (*nodeIdentifyR*)

- Download the R-package via
- https://github.com/JasperNaberman/nodeIdentifyR

- Main developer: Jasper Naberman

Two types of interventions

- *Alleviating* intervention represents a symptom-specific clinical treatment intervention.
  - Treatment strategy: What symptom should be treated first?

- *Aggravating* intervention represents the impact of a stressful life event on a specific symptom.
  - Prevention strategy: What is the vulnerability of the system?

Gaby Lunansky | g.lunansky@uva.nl | University of Amsterdam

Research questions

We present an algorithm that uses simulation-based interventions to study:

(1) whether symptoms have distinct projected influences on the behavior of the network, and if so,

(2) which symptom has the most substantial projected effect after an alleviating and aggravating intervention

Gabriela Lunansky | g.lunansky@uva.nl | University of Amsterdam

NodeIdentifyR Algorithm (NIRA)

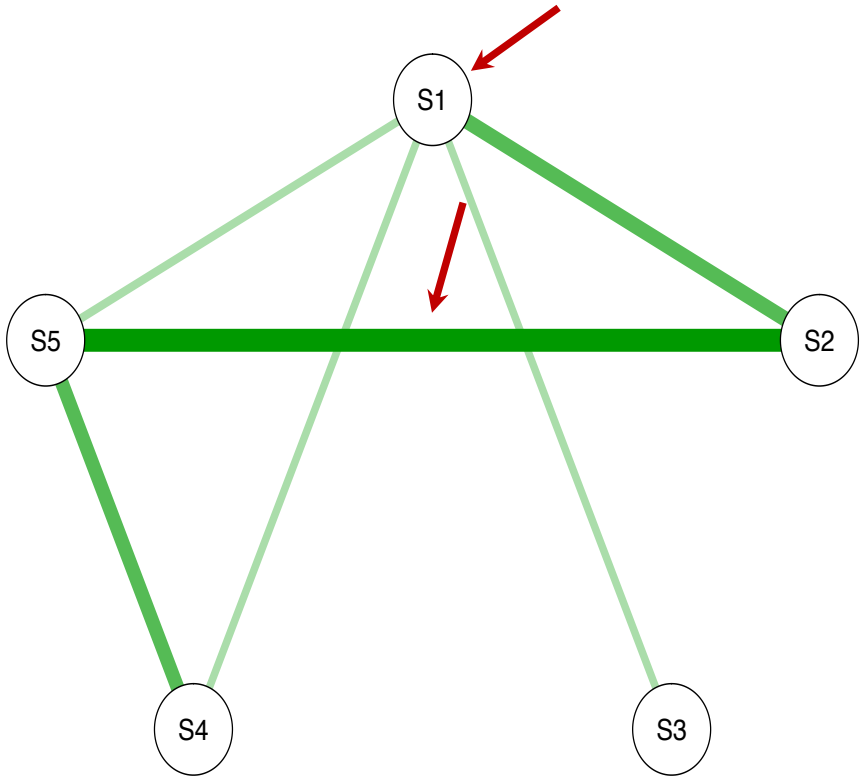
How does the algorithm work?

Applying the algorithm to data

Gaby Lunansky | g.lunansky@uva.nl |

Methods

- Node IdentifyR Algorithm (NIRA)
- Ising model (binary data)
  - X = {0,1}
- Dynamics of the Ising model depend on parameters of the **edges** and parameters of the **nodes.**
- NIRA alters the node parameters
  - Alleviating intervention: *decrease* the probability that a symptom is present
  - Aggravating intervention: *increase* the probability that a symptom is present



Gaby Lunansky | g.lunansky@uva.nl | University of Amsterdam

Methods - Ising Model Dynamics

The Ising model for two nodes (X_1, X_2) is given by formula (1), which extends to n nodes

(Haslbeck, Epskamp, Marsman, & Waldorp, 2020)

- $P(X_1, X_2) = \frac{1}{Z} \exp\{\tau_1 X_1 + \tau_2 X_2 + W_{12} X_1 X_2\}$ (1)

- Symptom spread depends on the *edge weight* parameters ($W_{i,j}$) and *threshold parameters* (τ_i)

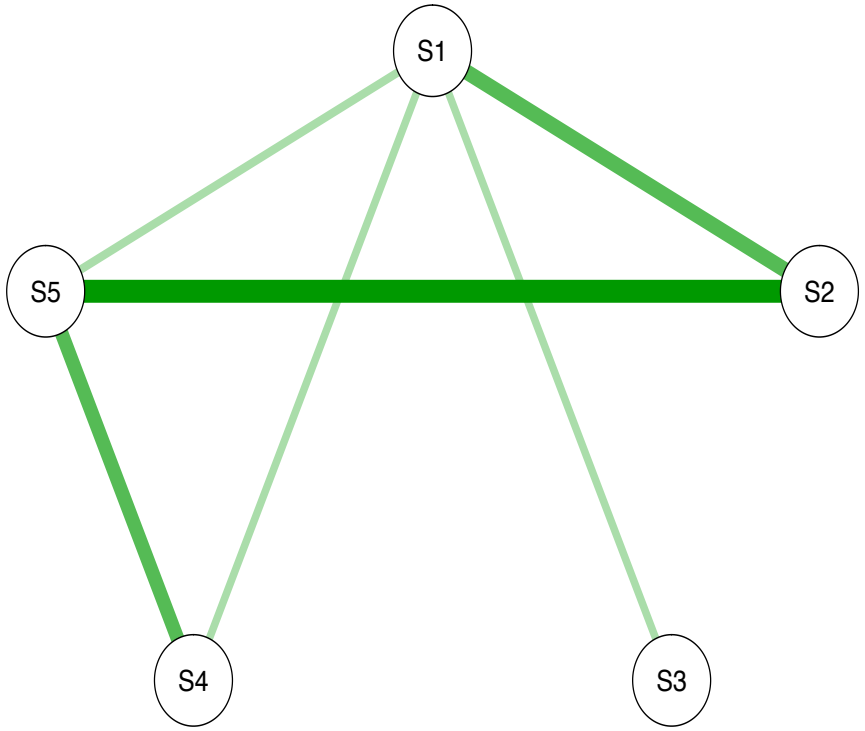
Methods – NIRA Interventions

- Symptom spread depends on the *edge weight* parameters ($W_{i,j}$) and *threshold parameters* (τ_i)
- Alleviating intervention: *decrease* the probability that a symptom is present
- Aggravating intervention: *increase* the probability that a symptom is present

Gaby Lunansky | g.lunansky@uva.nl | University of Amsterdam

Methods – Node IdentifyR Algorithm (NIRA)

1. Collect data and estimate an Ising model
    - This is our **baseline** model
2. Simulate data from the baseline model (5000 observations)
    - Compute overall sum score
3. Alter the threshold parameter of symptom *i*, simulate data (5000 observations)
    - Compute overall sum score
4. Repeat systematically for every node
5. Check outcome



Gaby Lunansky | g.lunansky@uva.nl | University of Amsterdam

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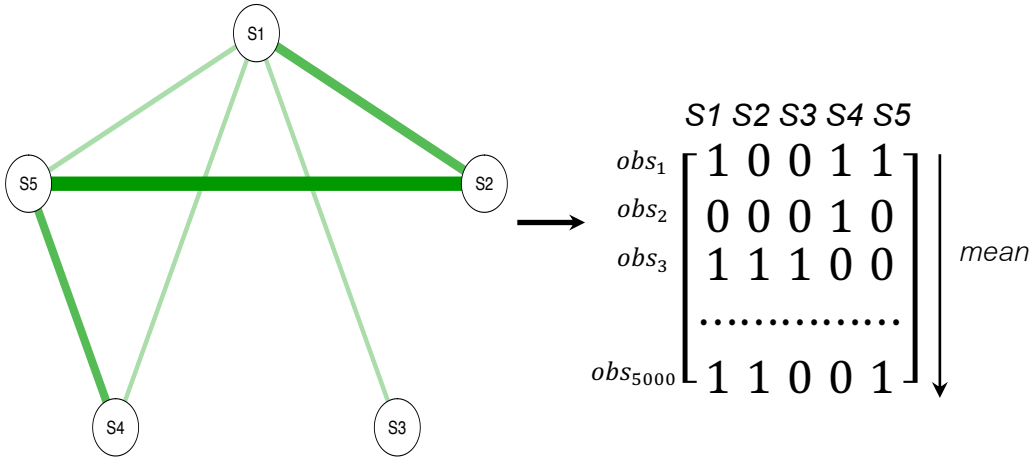

Gaby Lunansky | g.lunansky@uva.nl | University of Amsterdam

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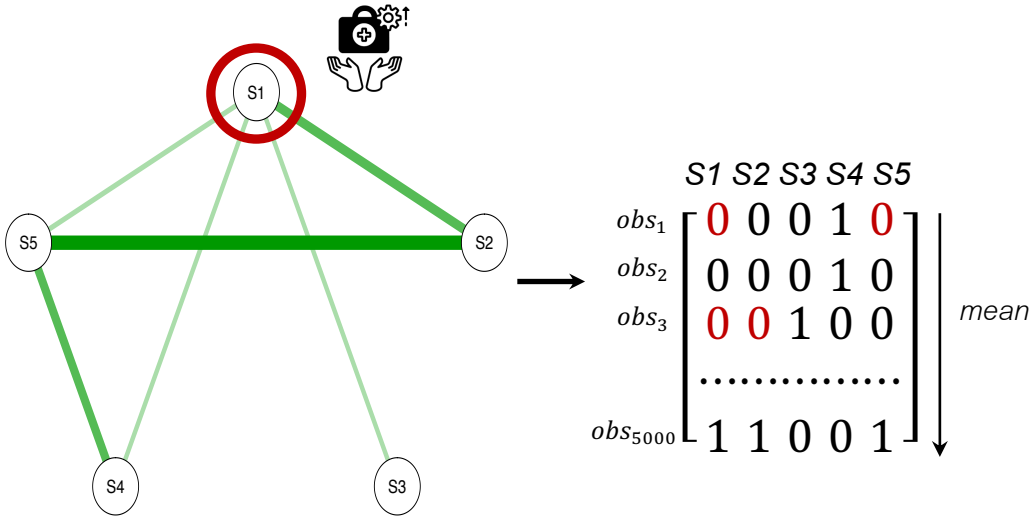

Gaby Lunansky | g.lunansky@uva.nl | University of Amsterdam

Methods – NIRA Interventions

- $\tau > 0$: Preference for being present
- $\tau < 0$: Preference for being absent

- Alleviating intervention: *decrease* the probability that a symptom is present
  - Subtract some value from the node's threshold parameter

- Aggravating intervention: *increase* the probability that a symptom is present
  - Add some value to the node's threshold parameter

- NIRA: 2 SD

Methods – Node IdentifyR Algorithm (NIRA)

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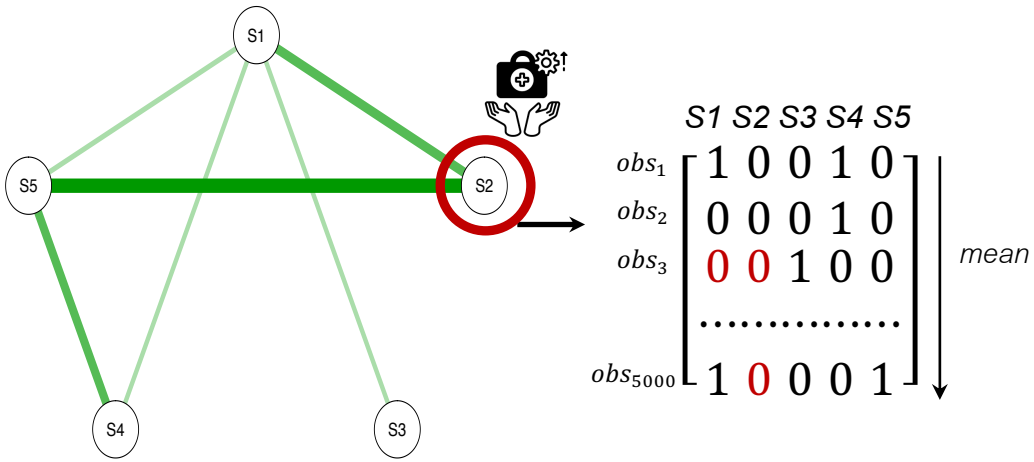

Gaby Lunansky | g.lunansky@uva.nl | University of Amsterdam

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Gaby Lunansky | g.lunansky@uva.nl | University of Amsterdam

Methods – Node IdentifyR Algorithm (NIRA)

- The NIRA outcome will be computed as the absolute difference between the baseline network's sum score (without interventions) and the sum scores after every threshold alteration

- The node-specific intervention with the highest absolute difference has the strongest projected effect on the network's behavior.

Gaby Lunansky | g.lunansky@uva.nl | University of Amsterdam

Methodology - Data

- Binarized MDD data by Kendler et al. - added sum score

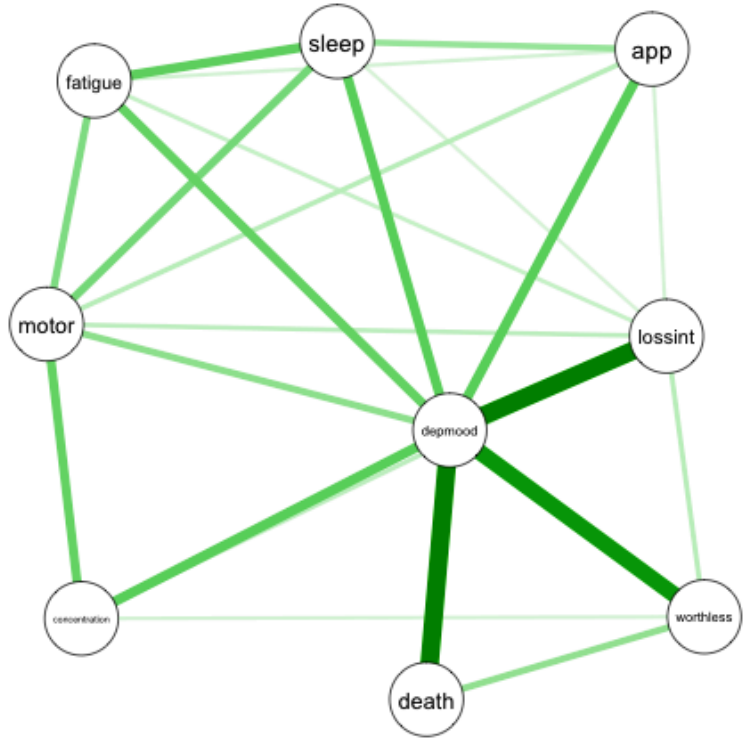
```
> data
      depmood lossint app sleep motor fatigue worthless concentration death sumscore
   1:       0       0   0     0     0       0         0             0     0        0
   2:       0       0   0     0     0       0         0             0     0        0
   3:       1       0   0     0     0       0         0             0     0        1
   4:       0       0   0     0     0       0         0             1     0        1
   5:       0       0   1     0     0       1         0             0     0        2
  ---
8969:       0       0   0     0     0       0         0             0     0        0
8970:       0       0   0     0     0       0         0             0     0        0
8971:       0       1   0     0     0       0         0             0     0        1
8972:       1       1   0     1     0       0         1             0     1        5
8973:       0       0   0     0     0       0         0             0     0        0
```

- Around 86% classified as 'healthy' (sum score < 5)

Slide by Jasper Naberman

Methodology - Data

- Yields the following network structure using IsingFit():
- This is also the algorithm input:



	depmood	lossint	app	sleep	motor	fatigue	worthless	concentration	death
depmood	0.0000000	2.1487858	1.0869654	1.0595045	0.7253899	0.9944696	1.8738643	1.0899825	2.1653365
lossint	2.1487858	0.0000000	0.2959167	0.2816010	0.4301821	0.3708953	0.4673973	0.4311141	0.0000000
app	1.0869654	0.2959167	0.0000000	0.6431836	0.4689972	0.3076062	0.0000000	0.0000000	0.0000000
sleep	1.0595045	0.2816010	0.6431836	0.0000000	0.8673246	1.0315549	0.0000000	0.0000000	0.0000000
motor	0.7253899	0.4301821	0.4689972	0.8673246	0.0000000	0.7943297	0.0000000	0.9855893	0.0000000
fatigue	0.9944696	0.3708953	0.3076062	1.0315549	0.7943297	0.0000000	0.0000000	0.0000000	0.0000000
worthless	1.8738643	0.4673973	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.3055207	0.7005526
concentration	1.0899825	0.4311141	0.0000000	0.0000000	0.9855893	0.0000000	0.3055207	0.0000000	0.0000000
death	2.1653365	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.7005526	0.0000000	0.0000000

Weight adjacency matrix; the visualised network structure in numbers.

depmood	lossint	app	sleep	motor	fatigue	worthless	concentration	death
-2.376127	-3.141440	-2.593312	-2.908276	-2.941380	-2.798122	-4.261626	-3.898869	-5.737949

Threshold vector

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Methodology - Algorithm

Response simulation

1. Select a node from the network structure
    A. Perturbate the τ parameter of that single node (+ or -)
    B. Sample 5000 Ising model states using the new structure
2. Continue with the next node in the network (step 2 - *n*)
3. Lastly, sample 5000 Ising model states with all original network parameters

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Methodology - Algorithm

Sum score calculation

- We get the following data structure:
  - A list with dataframes of 5000 rows ("participants") and *n nodes* columns

- Next step: calculate the sum score for every row in every dataframe.

```
$original
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9]
[1,]    0    0    0    0    0    0    0    0    0
[2,]    1    1    0    0    0    0    0    0    0
[3,]    0    0    0    1    0    0    0    1    0
[4,]    0    0    0    0    0    0    0    0    0
[5,]    0    0    0    0    0    0    0    0    0
[6,]    1    0    0    1    0    0    1    0    0

$depmood
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9]
[1,]    0    0    0    0    0    0    0    0    0
[2,]    0    0    0    0    0    0    0    0    0
[3,]    0    1    0    0    1    0    0    0    0
[4,]    0    0    0    0    0    0    0    0    0
[5,]    0    1    0    0    0    0    0    0    0
[6,]    0    0    1    0    0    0    0    0    0

$lossint
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9]
[1,]    0    0    0    0    0    0    0    0    0
[2,]    0    0    1    0    0    0    0    0    0
[3,]    0    0    0    0    0    0    0    0    0
[4,]    0    0    0    0    0    0    0    0    0
[5,]    1    0    1    1    1    1    0    0    0
[6,]    1    0    0    0    1    0    0    0    0
```

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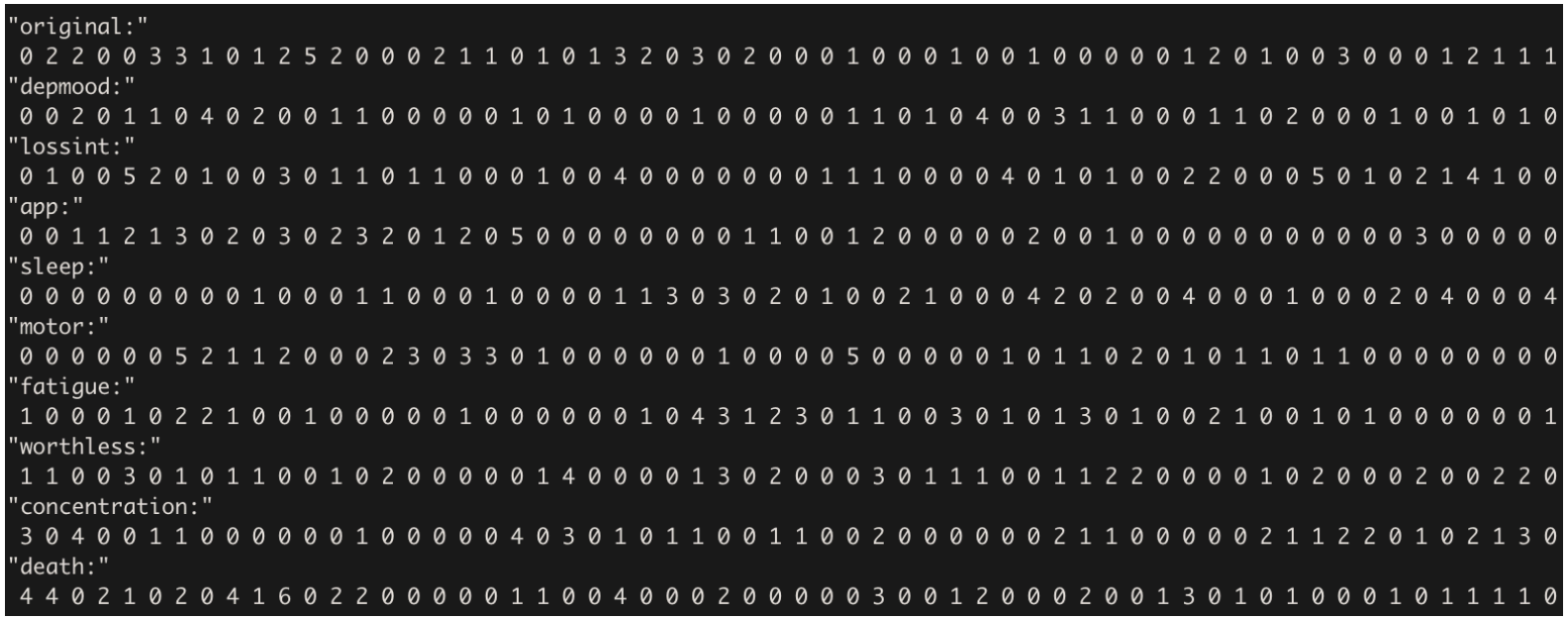
Methodology - Algorithm

Sum score calculation

- We end up with a vector of sum scores for every node iteration:



- Every sum score belongs to a single simulated "participant"

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Methodology - Algorithm

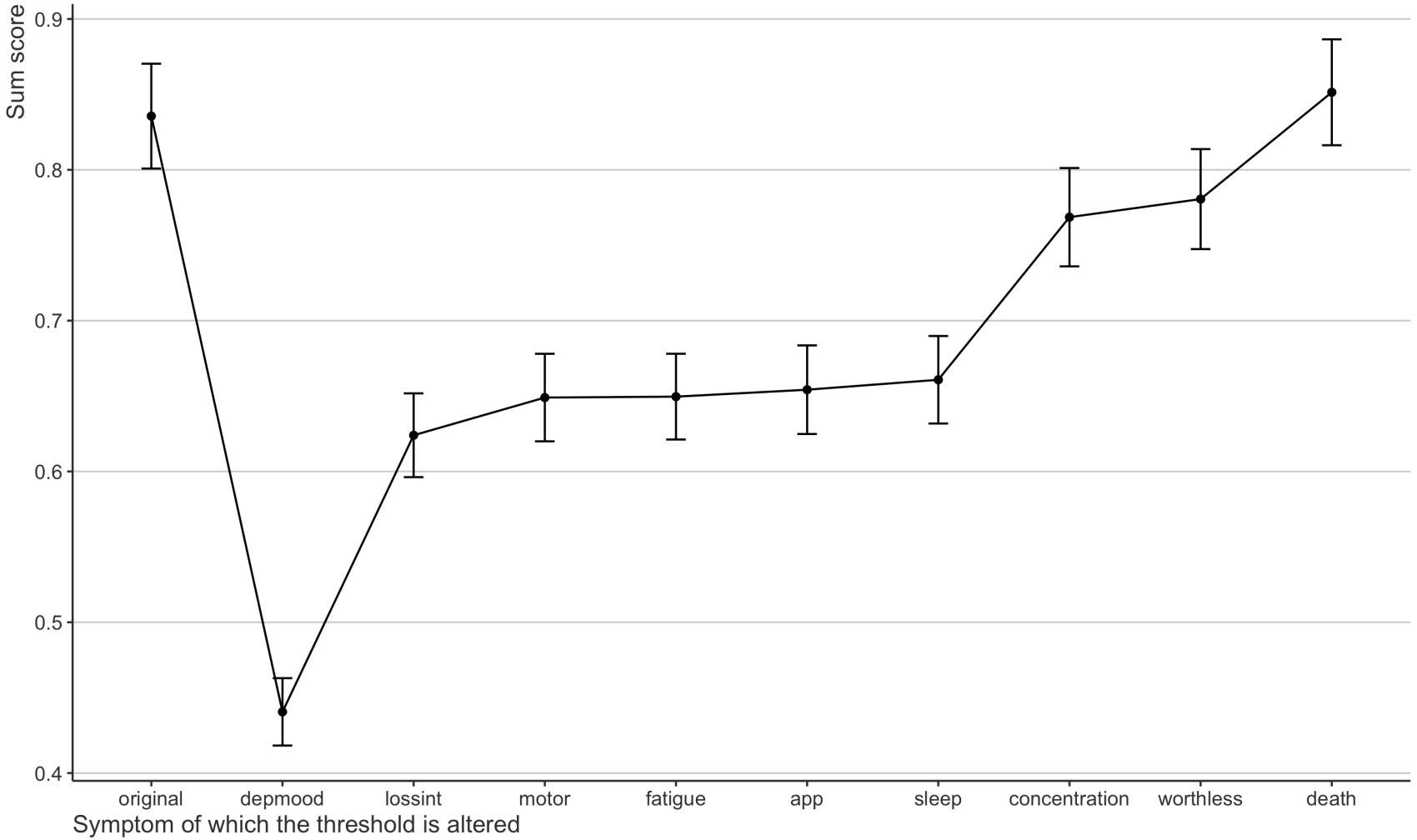
Visualisation preparation

- After some data wrangling we will be ready for plotting.
- We calculate the average and 95% CI

thresholdIteration	meanSumscore	ciLower	ciUpper
original	0.8356	0.8008334	0.8703666
depmood	0.4406	0.4182441	0.4629559
lossint	0.6240	0.5962139	0.6517861
motor	0.6490	0.6199747	0.6780253
fatigue	0.6496	0.6211604	0.6780396
app	0.6542	0.6248320	0.6835680
sleep	0.6608	0.6317807	0.6898193
concentration	0.7686	0.7359962	0.8012038
worthless	0.7806	0.7474512	0.8137488
death	0.8514	0.8162951	0.8865049

Slide by Jasper Naberman

Methodology - Visualisation



Slide by Jasper Naberman

Empirical illustration

Using a network of PTSD symptoms

Gaby Lunansky | g.lunansky@uva.nl |

Empirical Illustration

PTSD symptoms

4910 adolescents (49.5% boys; mean age 11.4±1.4 years)

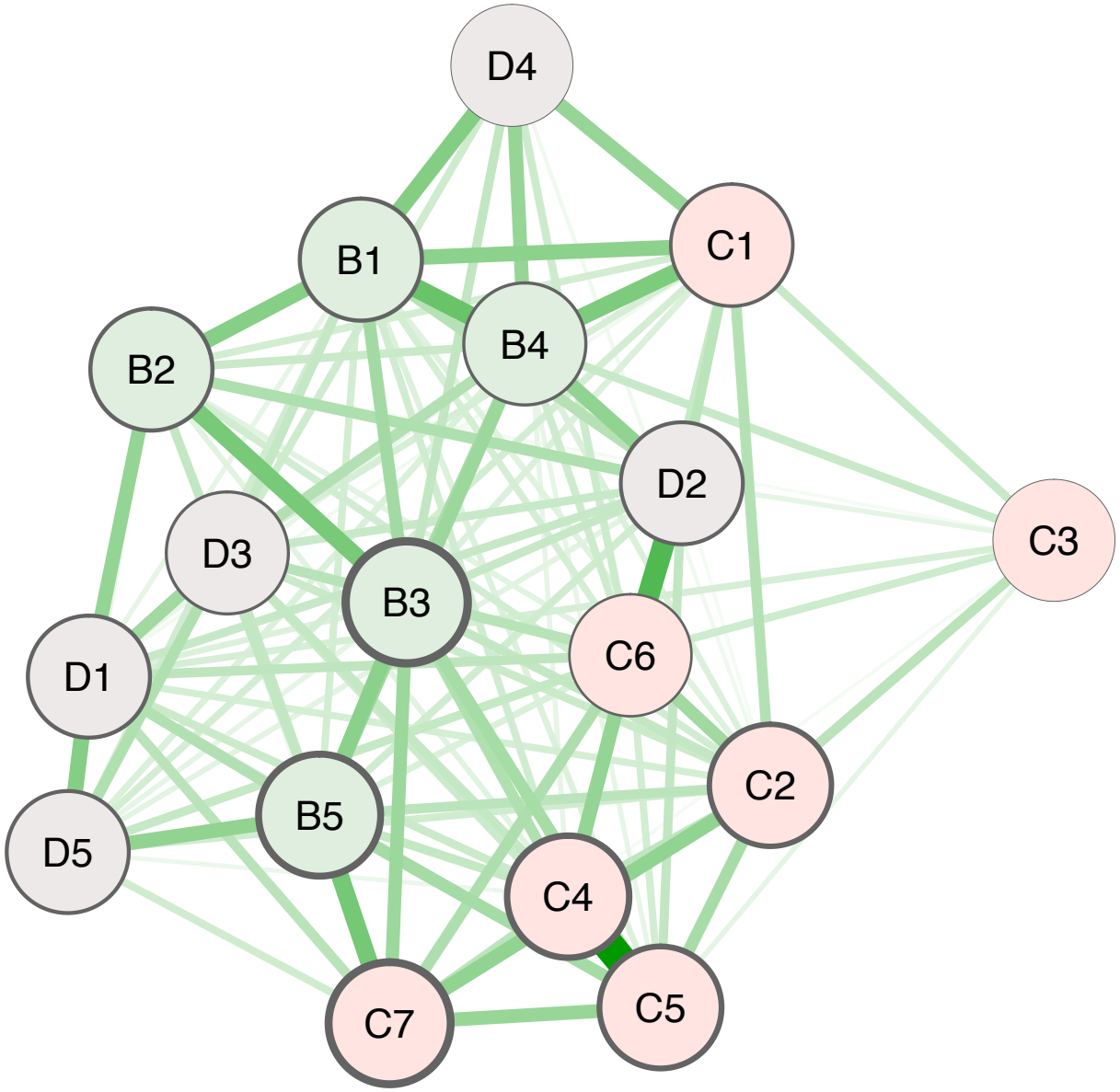
Experienced the Wenchuan earthquake (2008)

PTSD Reaction Index

17 PTSD symptoms from three subdomains

Intrusion, Avoidance, and Arousal

Binarized data



Criterion B (Intrusion)
- B1: Intrusive thoughts
- B2: Nightmares
- B3: Flashbacks
- B4: Emotional reactivity
- B5: Physical reactivity

Criterion C (Avoidance)
- C1: Avoidance of thoughts
- C2: Avoidance of reminders
- C3: Amnesia for aspects
- C4: Loss of interest
- C5: Feeling distant
- C6: Feeling numb
- C7: Foreshortened future

Criterion D (Arousal)
- D1: Sleep disturbance
- D2: Irritability
- D3: Difficulty concentrating
- D4: Hypervigilance
- D5: Exaggerated startle

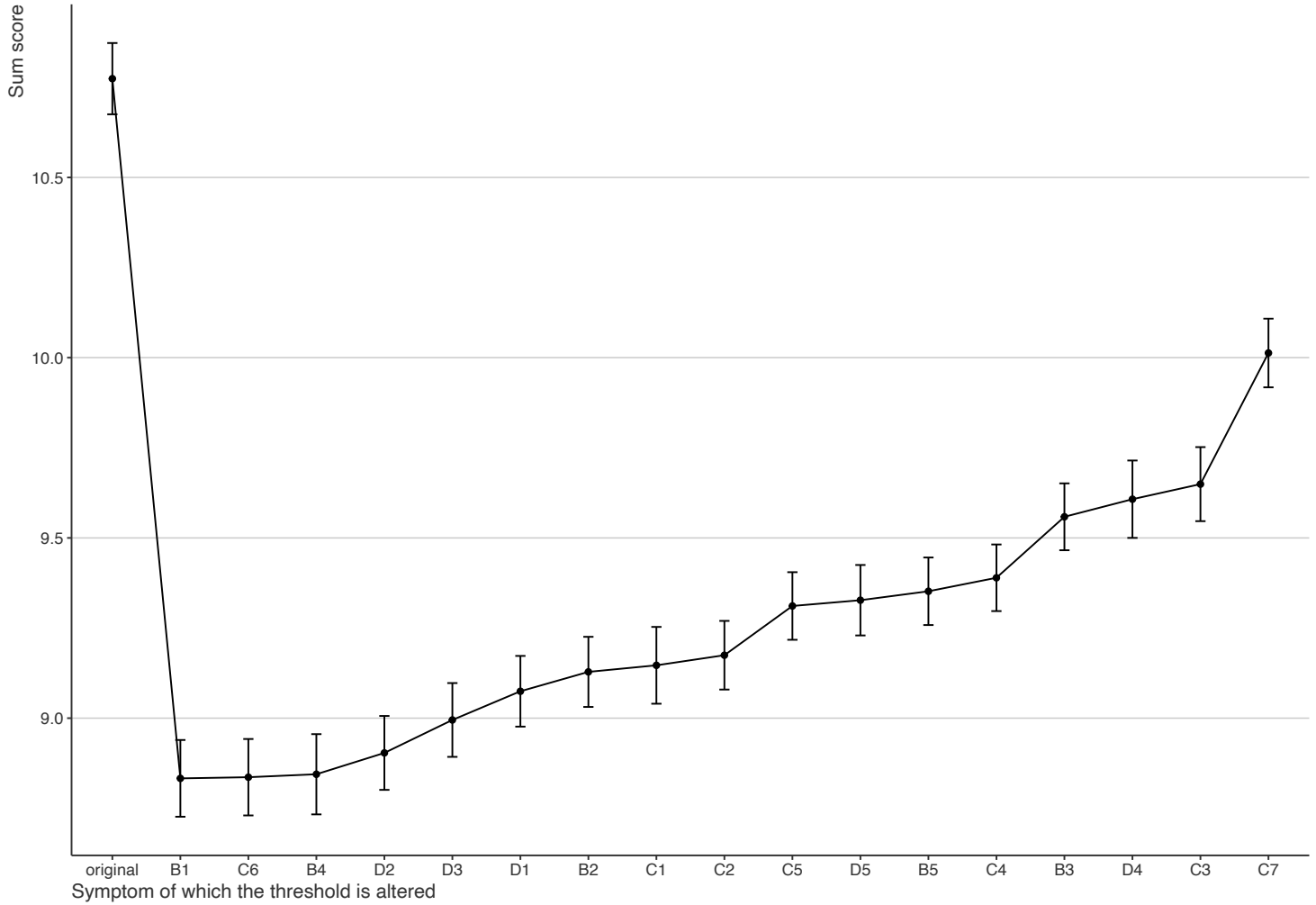
Gaby Lunansky | g.lunansky@uva.nl |

Two types of interventions

- *Alleviating* intervention represents a clinical intervention
  - Intervention: Decrease a symptom's probability to be present

- *Aggravating* intervention represents a stressful life event
  - Intervention: Increase a symptom's probability to be present

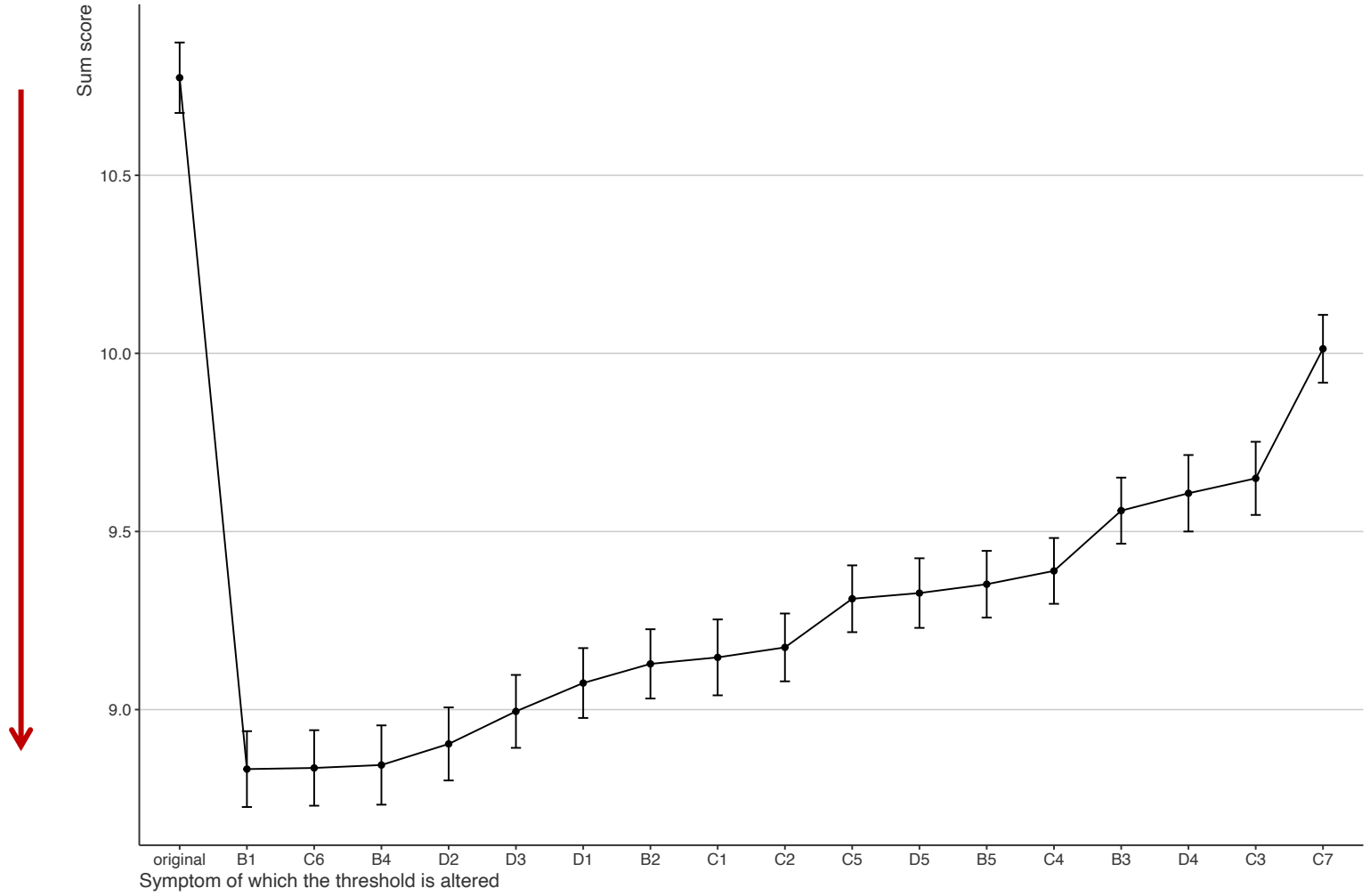
Results – Alleviating interventions



Gaby Lunansky | g.lunansky@uva.nl |

Results - Alleviating interventions

Propelling effects?



Gaby Lunansky | g.lunansky@uva.nl |

Two types of interventions

- *Alleviating* intervention represents a clinical intervention
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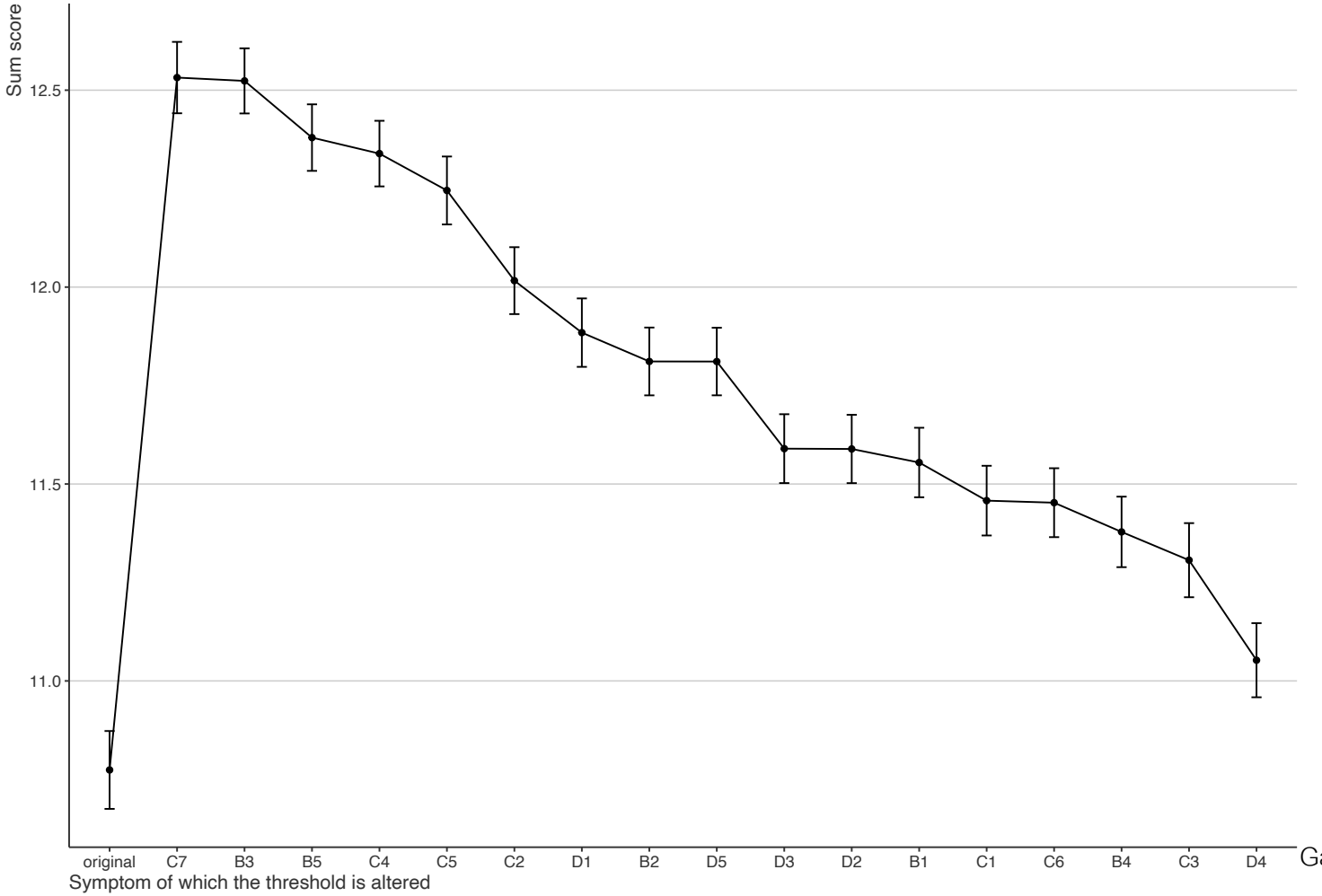
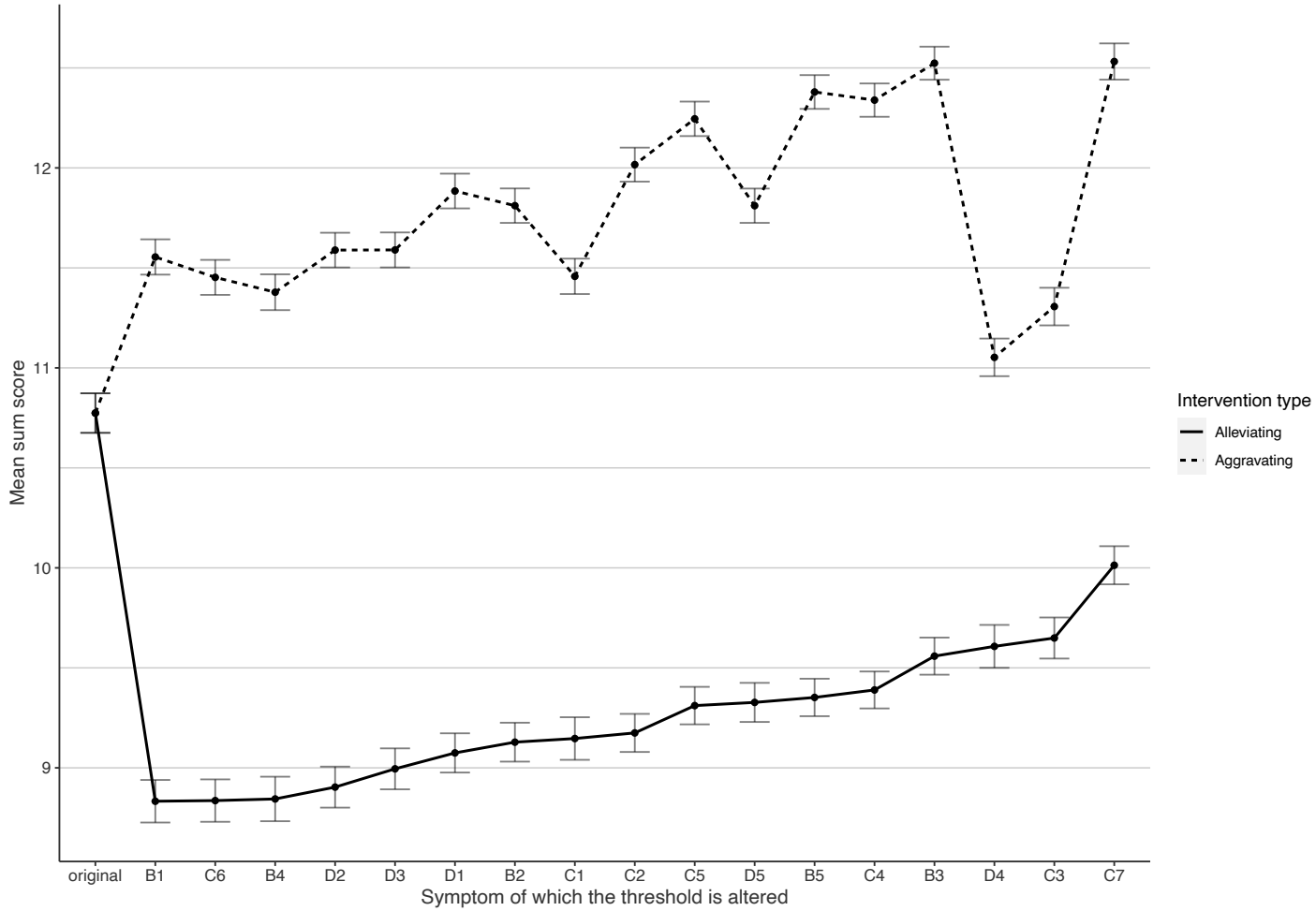
- *Aggravating* intervention represents a stressful life event
  - Intervention: Increase a symptom's probability to be present

Results – Aggravating interventions



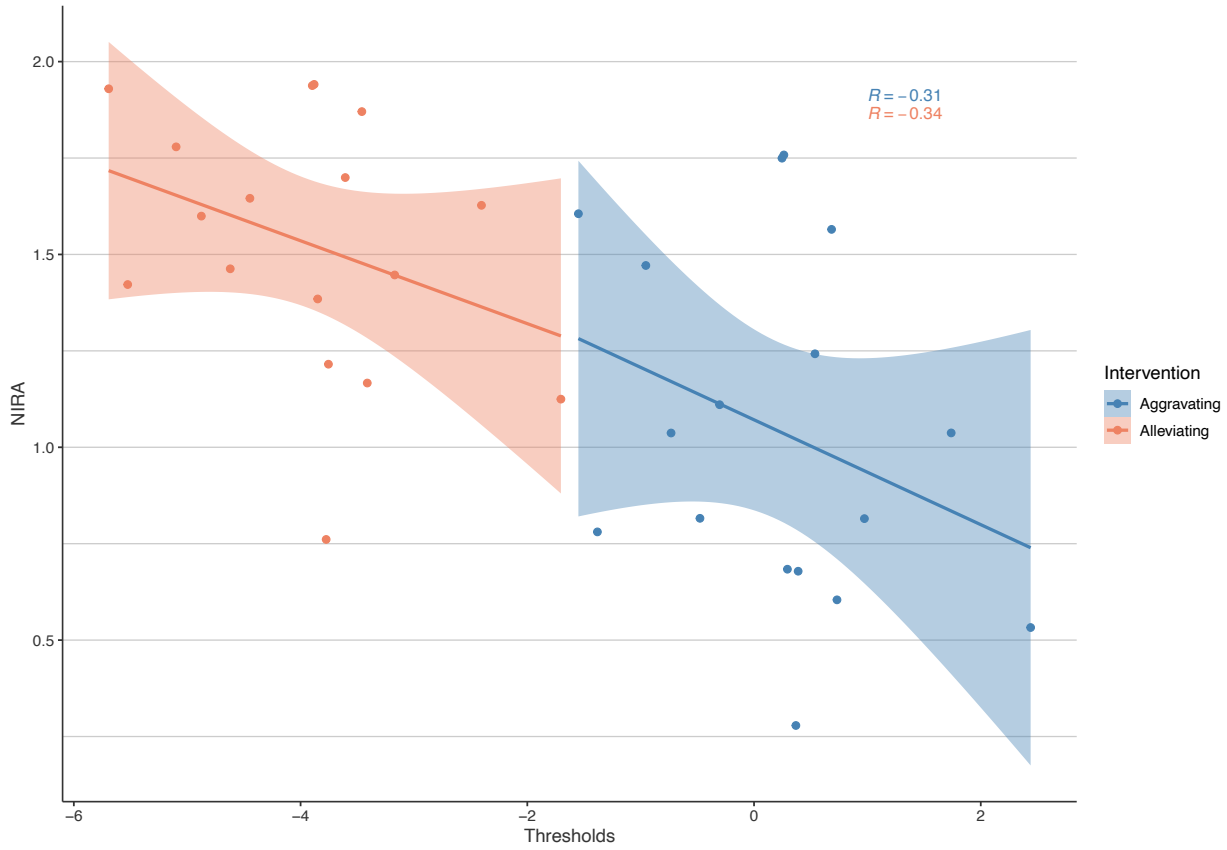
Gaby Lunansky | g.lunansky@uva.nl |

Compare effects from both interventions



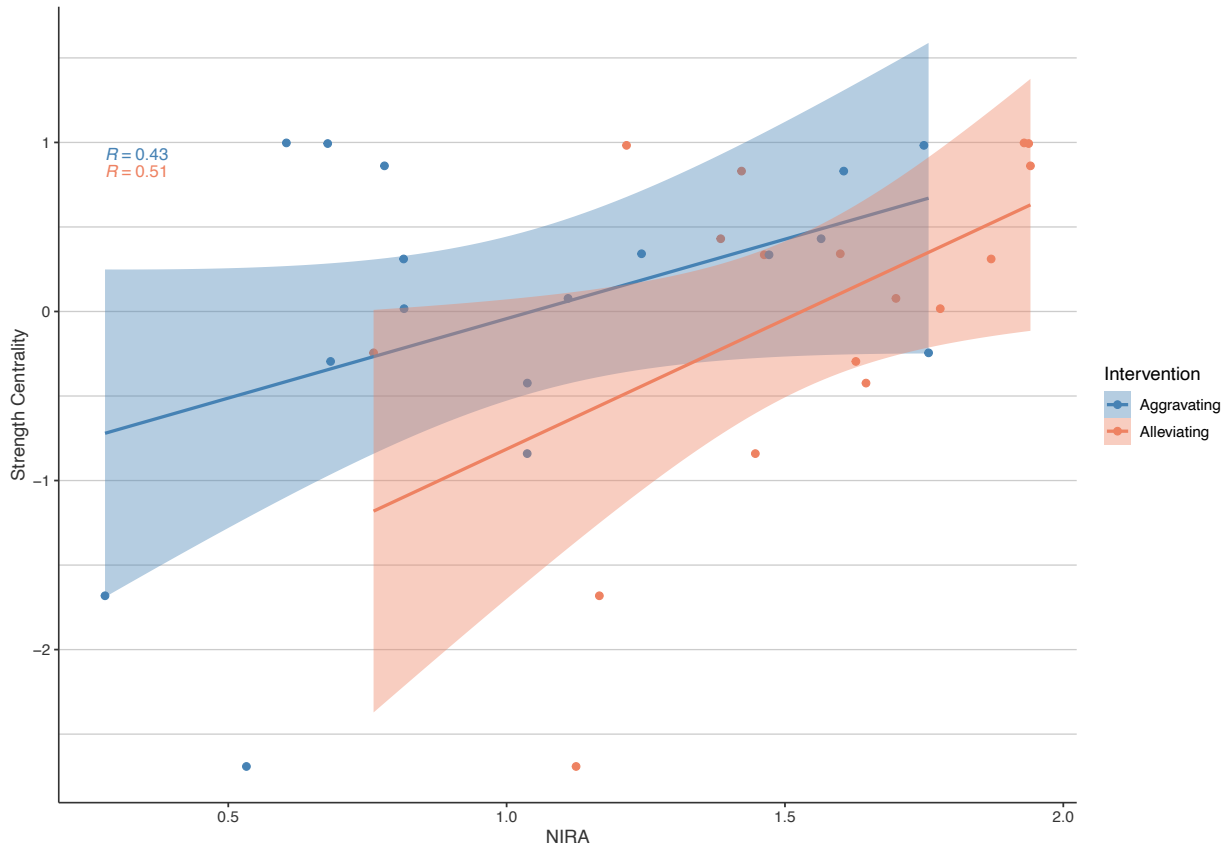
Gaby Lunansky | g.lunansky@uva.nl |

Correlation with original threshold parameters



Gaby Lunansky | g.lunansky@uva.nl |

Correlation with strength centrality



Gaby Lunansky | g.lunansky@uva.nl |

Conclusions

- We presented a straightforward, simulation-based technique to study the projected effects of symptom-specific interventions on the overall behavior of psychopathology networks.

- As an empirical illustration, we applied the technique to an empirical dataset containing PTSD symptom assessments.
  - Potential propelling effects
  - Interventions have different projected effects on different nodes

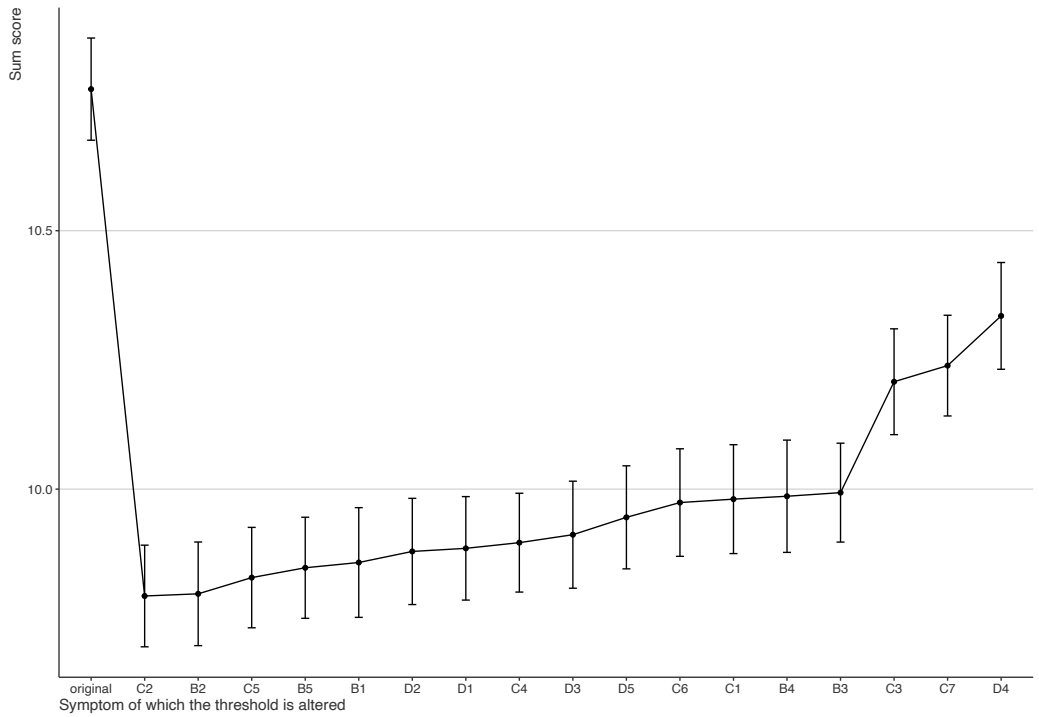
Gaby Lunansky | g.lunansky@uva.nl |

Limitations

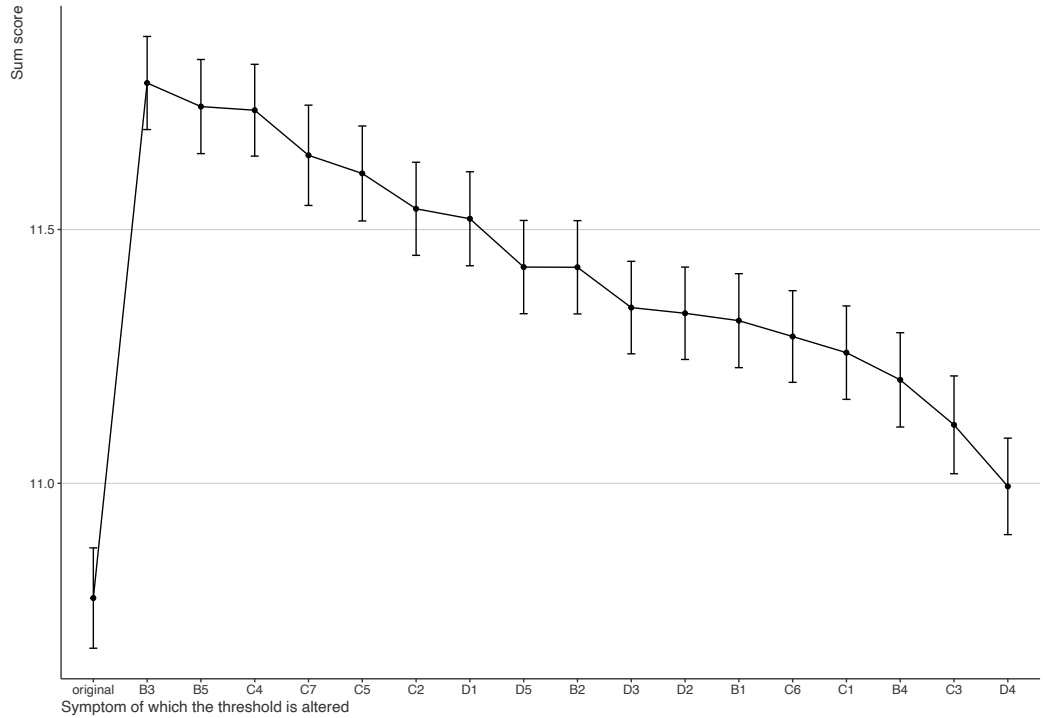
- For now, only with the Ising model, so binarized data
- Group models!
  - Limit heterogeneity?
- “Fat hands” problem
- The effect of the interventions is determined by their strength, so results (propelling effects) are more minor with smaller interventions
- The method needs to be empirically validated
  - Only generate hypotheses (but very specific and testable!)

Sensitivity analysis with smaller threshold alteration (1 SD)

Alleviating interventions



Aggravating interventions



Gabriela Lunansky | g.lunansky@uva.nl | University of Amsterdam

?

Simulating interventions: Reflection

Gaby Lunansky | g.lunansky@uva.nl |

What do you think?

Should we work on novel methods that simulate interventions (such as NIRA) in clinical settings, if the models are not yet empirically validated?

Gaby Lunansky | g.lunansky@uva.nl |

Thank you for your attention!

www.gabylunansky.com

g.lunansky@uva.nl

@gabylunansky