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Measuring resilience through time series data

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Declaration of Conflict of Interest

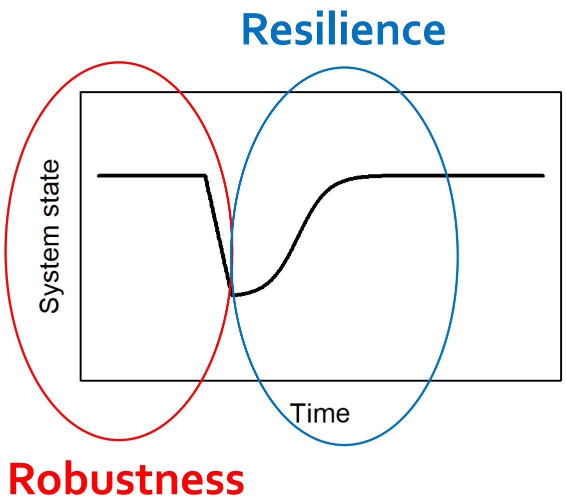
- Founder and CEO at Oken Health

Defining resilience

- **Canalized resilience**: Specific pathways that have evolved to allow organisms to respond to various stressors

- **Systemic resilience**: Emergent property of a dynamic system that cannot be traced to particular pathways

Robustness vs. Resilience

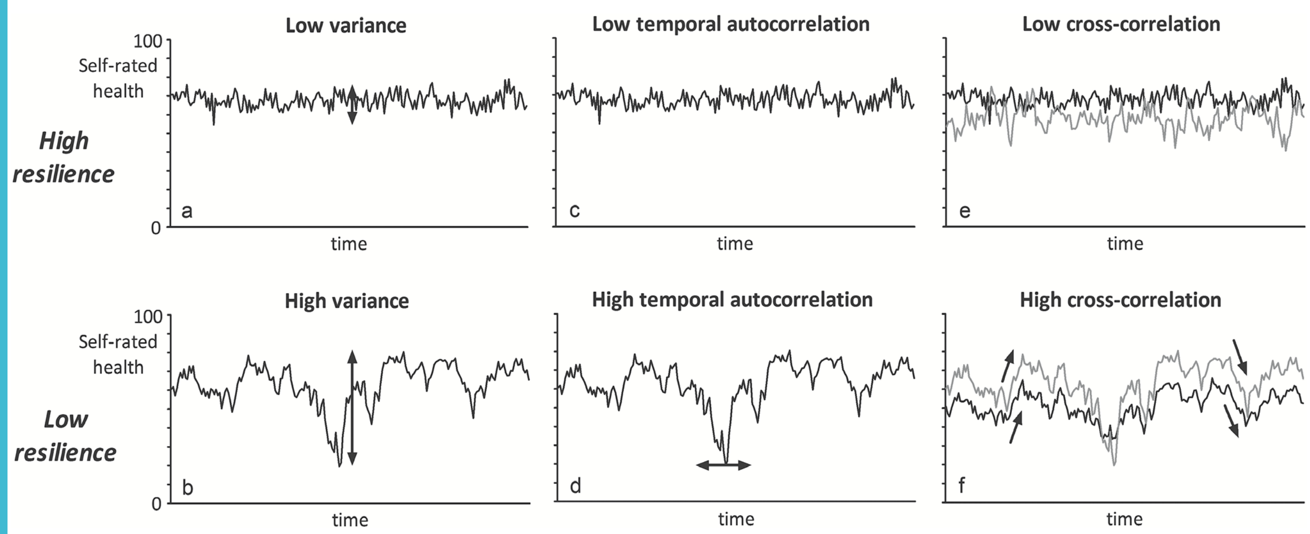


Micro- vs. macro resilience

Ives, A. R. (1995). Measuring resilience in stochastic systems. *Ecological Monographs*, *65*(2), 217-233.

Early warning signs of critical transitions

- Based on ecological theory on resilience



Gijzel et al. *J Gerontol A Biol Sci Med Sci*, 72 (7) 2017,991–996. https://doi.org/10.1093/gerona/glx065

Scheffer, M. (2020). *Critical transitions in nature and society* (Vol. 16). Princeton University Press.

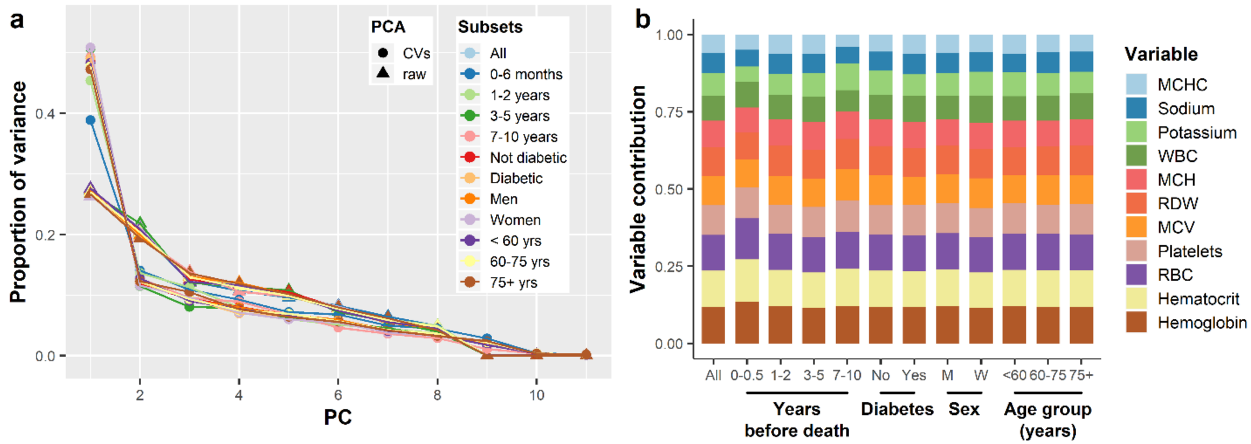
Scheffer, M. et al. (2012). Anticipating critical transitions. *Science*, *338*(6105), 344-348.

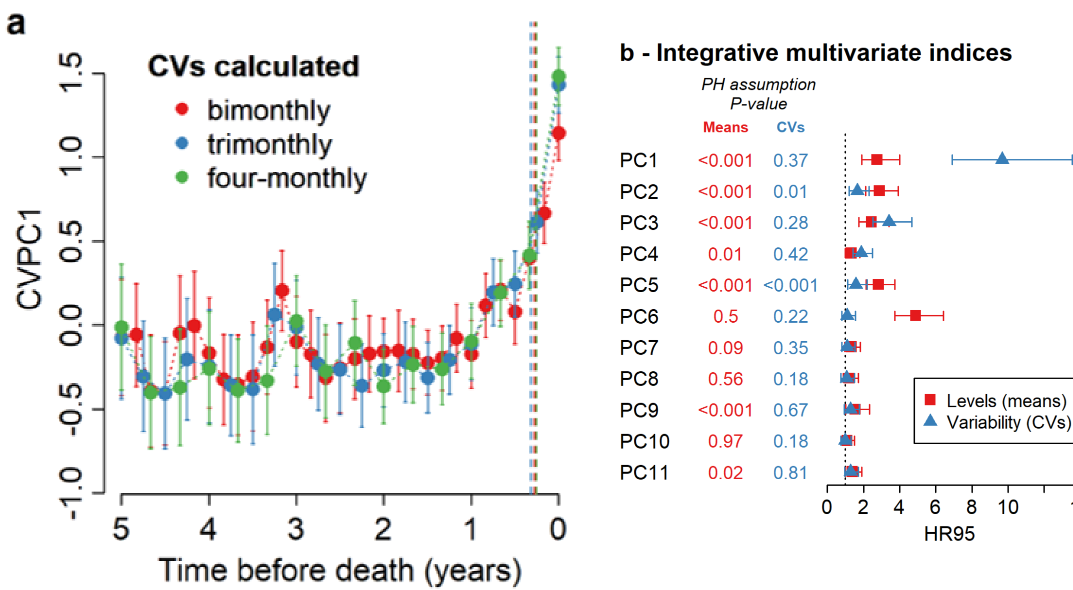
EWSs: Data

- Quebec: CIRESSS clinical database
  - Hemodialysis patients, 6+ months, 1997-2017
  - Bi-weekly panels of 11 biomarkers
  - 763 patients, ~56K visits, 409 deaths, 3127 hospitalizations

- Saitama, Japan: Hakuyukai Medical Corp.
  - Hemodialysis patients, 6+ months, June 2015- May 2016
  - Semi-monthly blood panels, 19 parameters
  - 580 patients, 109 frail

EWSs: Results





Cohen, A. A. et al. (2022). Synchrony of biomarker variability indicates a critical transition: Application to mortality prediction in hemodialysis. *Iscience*, *25*(6).

Schreiber, T. (2000). Measuring information transfer. *Physical review letters*, *85*(2), 461.

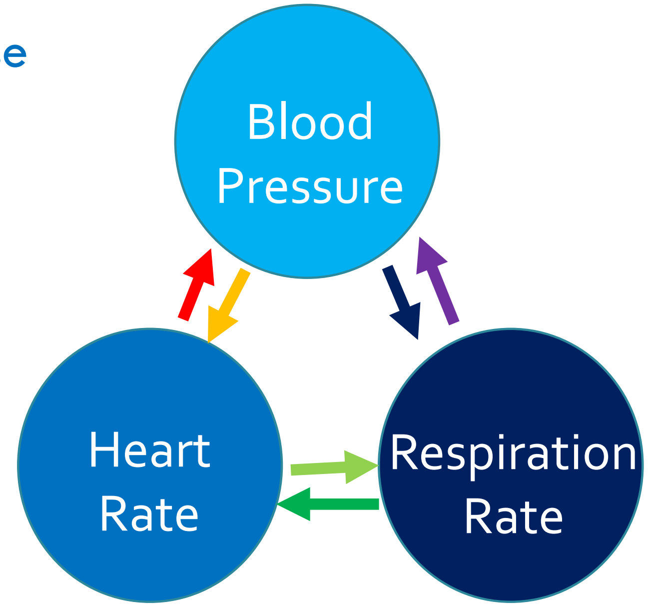
$$T_{J\rightarrow I}(k,l) = \sum_{i,j} p\left(i_{t+1}, i_t^{(k)}, j_t^{(l)}\right) \cdot log\left(\frac{p\left(i_{t+1} | i_t^{(k)}, j_t^{(l)}\right)}{p\left(i_{t+1} | i_t^{(k)}\right)}\right)$$

MiSBIE dataset

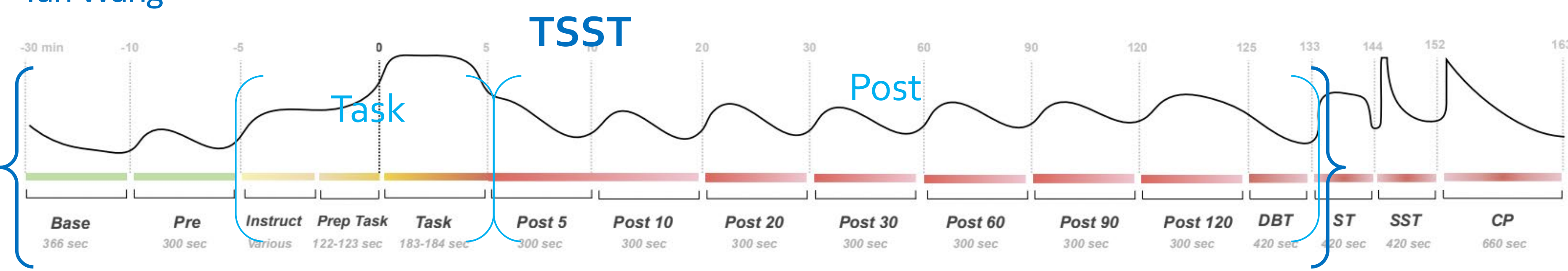
Transfer entropy

- Mitochondrial disease status

- $TE_{HR\rightarrow BP}$
- $TE_{BP\rightarrow HR}$
- $TE_{BP\rightarrow RSP}$
- $TE_{RSP\rightarrow BP}$
- $TE_{HR\rightarrow RSP}$
- $TE_{RSP\rightarrow HR}$



Collaborators:
Martin Picard
Sen Pei
Yan Wang



Results - Patient Status

Phase	Biomarker 1	Biomarker 2	Control	Deletion	Mutation	p_value_Mutation_Control	p_value_Deletion_Control
post	Bp	Hr	0.059	0.056	0.058	0.971	0.279
post	Bp	Rsp	0.059	0.051 ↓	0.046 ↓	0.019	0.043
post	Hr	Bp	0.071	0.073	0.063	0.136	1.000
post	Hr	Rsp	0.058	0.057	0.047 ↓	0.036	0.615
post	Rsp	Bp	0.057	0.050	0.046 ↓	0.047	0.192
post	Rsp	Hr	0.051	0.054	0.041 ↓	0.029	0.590
SST	Bp	Rsp	0.086	0.079	0.104 ↑	0.049	0.342
SST	Rsp	Bp	0.084	0.096	0.116 ↑	0.002	0.725
ST	Hr	Rsp	0.080	0.089	0.065 ↓	0.074	0.540

- Conducting Wilcox Test to see whether there is any **significant difference** between patients with different health statuses.
- In the **TSST post phase,** TE in the **mutation group** are significantly **lower than the control group**.
- In **SST,** TE in the mutation group are significantly **higher** than the control group.

Questions?

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