

Modeling Adolescent Executive Function Development Across Assessments and Datasets

Brenden Tervo-Clemmens, PhD

University of Minnesota

btervocl@umn.edu



@tervoclemmensb

Outline

Conceptual and methodological context for these questions.

Theories of human neurobehavioral development in adolescence

Non-linear modeling of lifespan trajectories

Foundational methods we have used to construct models across assessments and datasets.

R markdown and interactive examples

Extensions of these methods and looking forward to new directions.

Outline

Conceptual and methodological context for these questions.

Theories of human neurobehavioral development in adolescence

Non-linear modeling of lifespan trajectories

Foundational methods we have used to construct models across assessments and datasets.

R markdown and interactive examples

Extensions of these methods and looking forward to new directions.

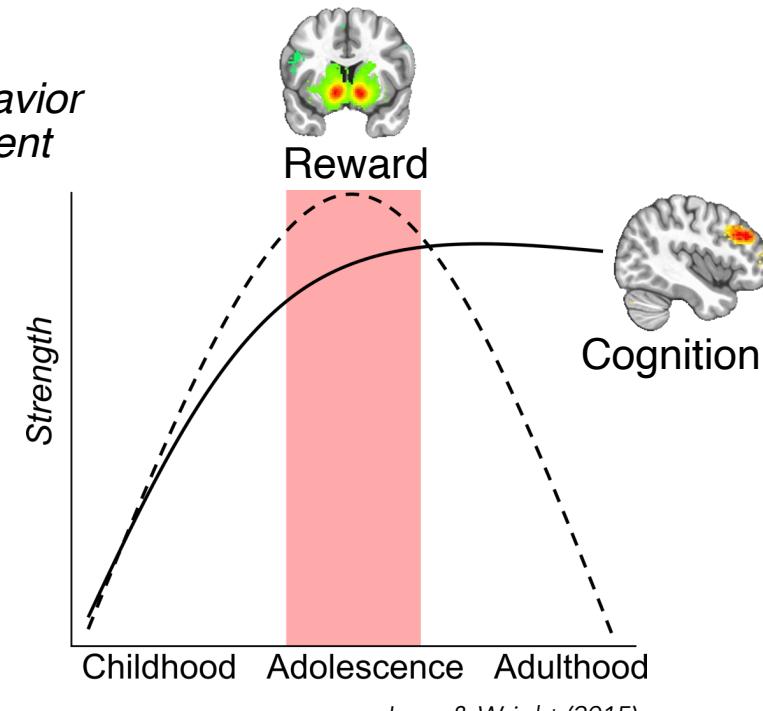
Adolescence



Adolescence



Brain-Behavior Development



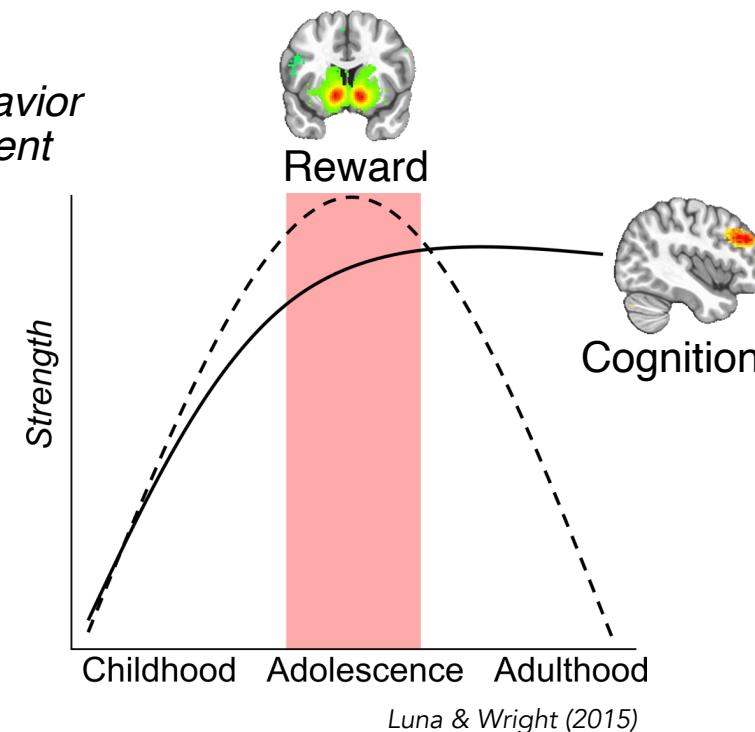
Adolescence



Mental Health/Substance Use Disorder Onset



Brain-Behavior Development



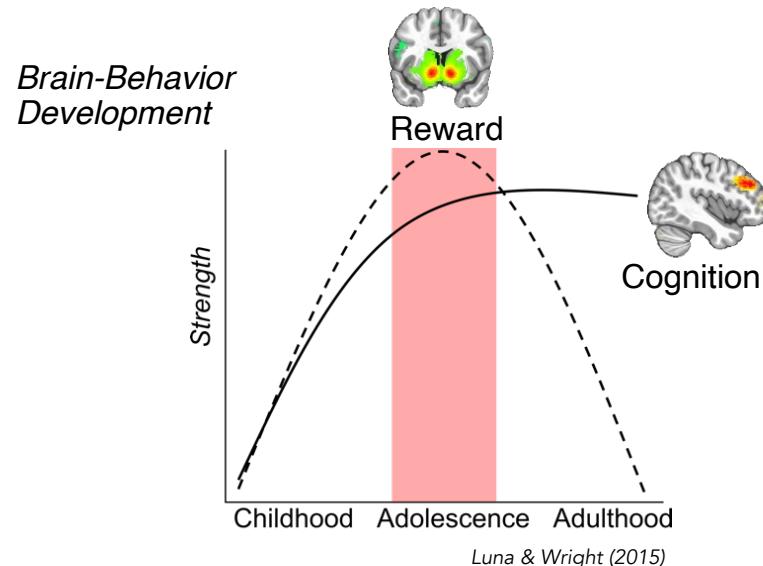
Luna & Wright (2015)

Paus et al 2008

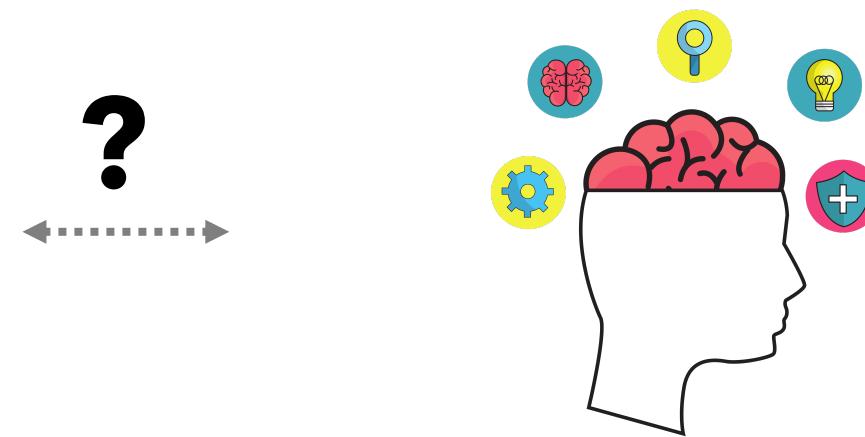
Adolescent Translational Science

Translating neurodevelopmental theory and research to clinical intervention remains challenging.

Basic Neurodevelopmental Science



Clinical Intervention with Adolescents



Challenges to Reproducibility

Increasing concerns in psychology and neuroscience on the reproducibility of findings further limits clinical translation.

RESEARCH ARTICLE

Estimating the reproducibility of psychological science

Open Science Collaboration^{*,†}

Power failure: why small sample size undermines the reliability of neuroscience

Katherine S. Button, John P. A. Ioannidis, Claire Mokrysz, Brian A. Nosek, Jonathan Flint, Emma S. J. Robinson & Marcus R. Munafò✉

Nature Reviews Neuroscience 14, 365–376 (2013) | [Cite this article](#)

Essay

Why Most Published Research Findings Are False

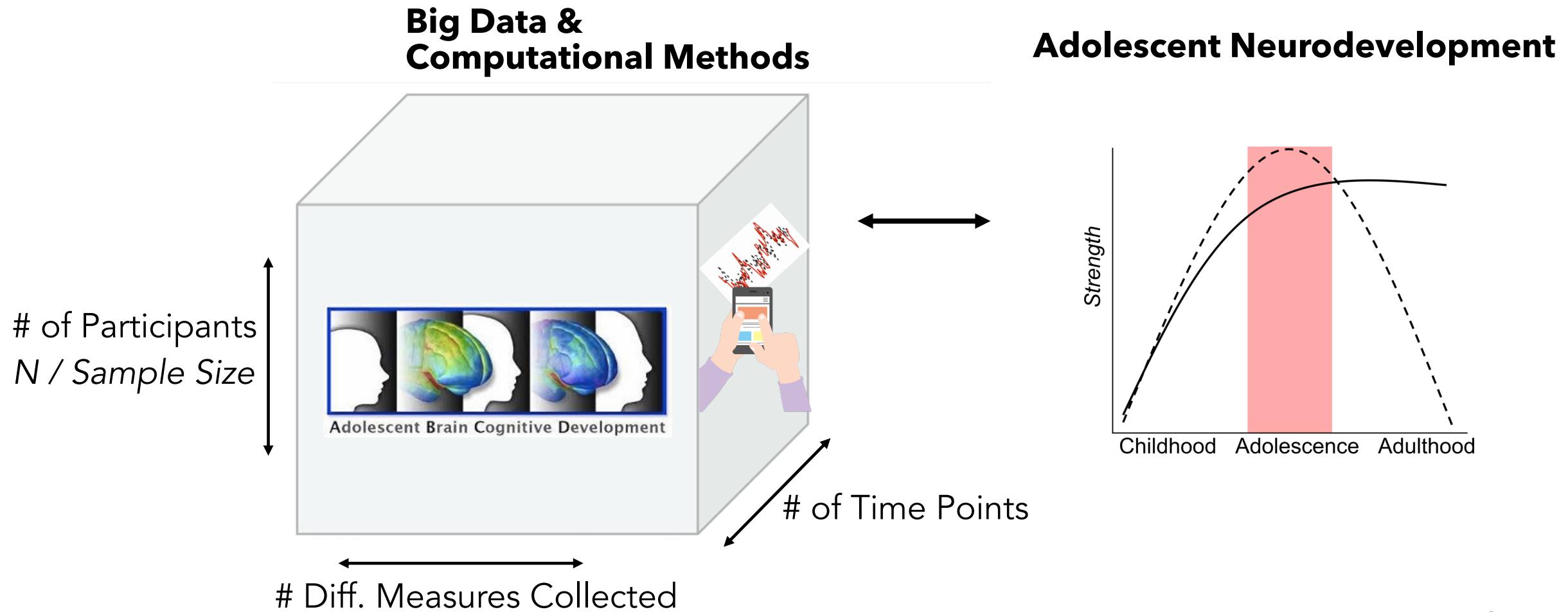
John P. A. Ioannidis



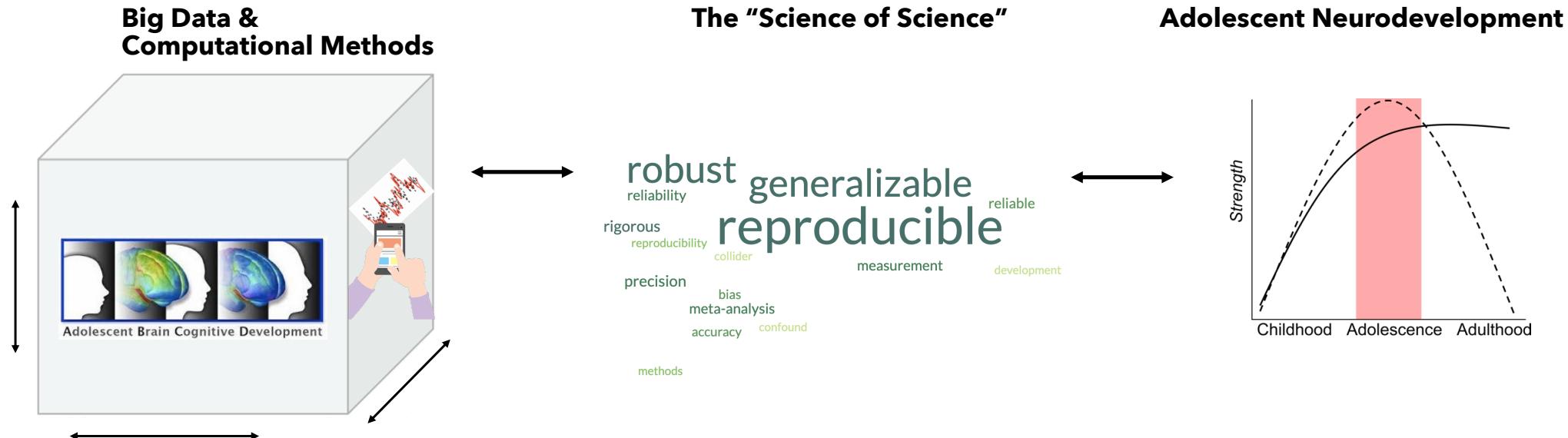
Clinical Intervention with Adolescents



Leveraging Big Data in Adolescent Transitional Science



Leveraging Big Data in Adolescent Transitional Science



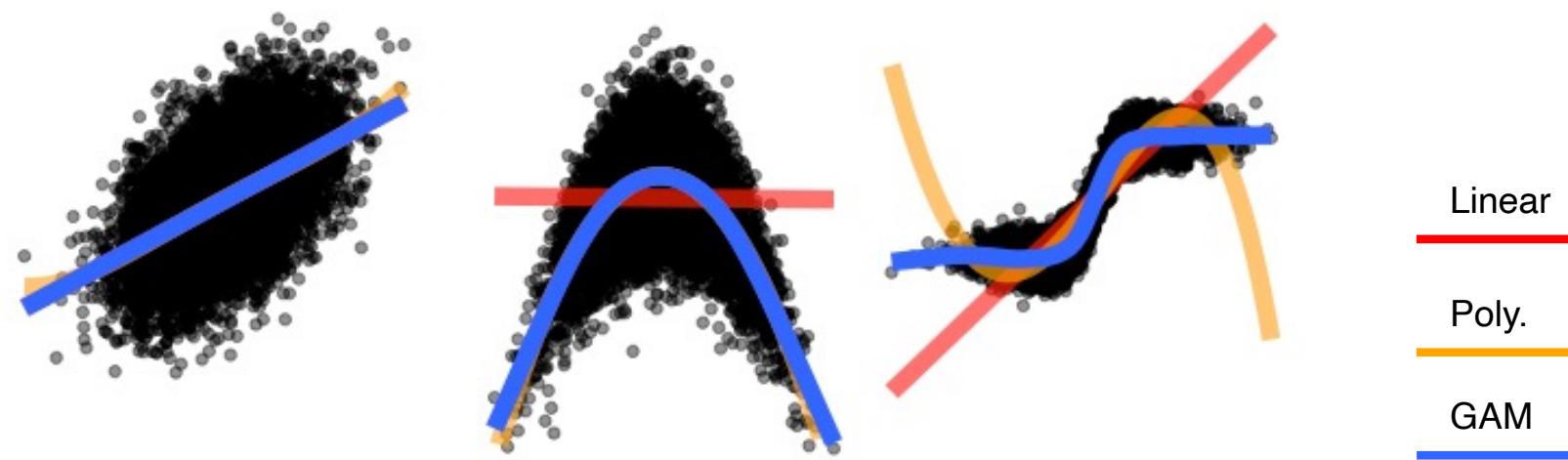
Lifespan non-linear modeling as insights into development periods

General Additive (Mixed) Models (GAM/GAMMs)¹

Non-linear modeling

Quantitatively defined functional form

Penalized splines

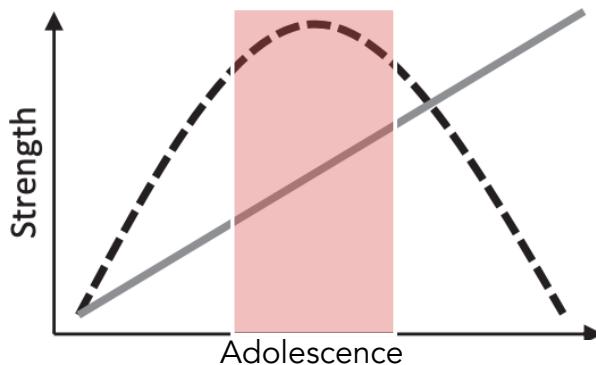


¹Wood, 2018, MCV Package

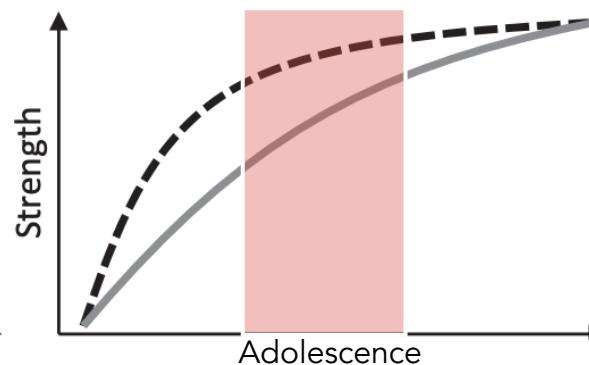
Neurobehavioral Theories of Adolescence

Clarifying neurodevelopmental processes of adolescence is essential for translating this research towards clinical care.

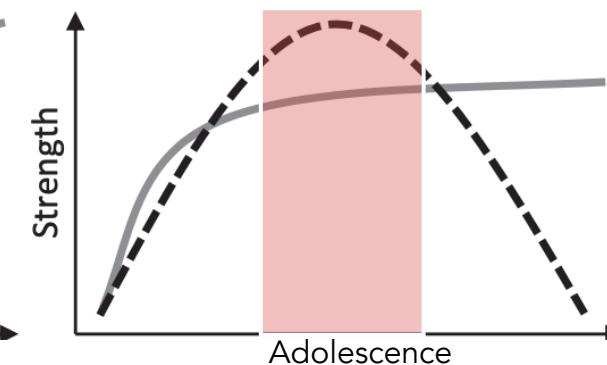
A. Dual Systems Model
(Steinberg, 2008)



B. Maturational Imbalance Model
(Casey et al., 2008)



C. Driven Dual Systems Model
(Luna & Wright, 2015)

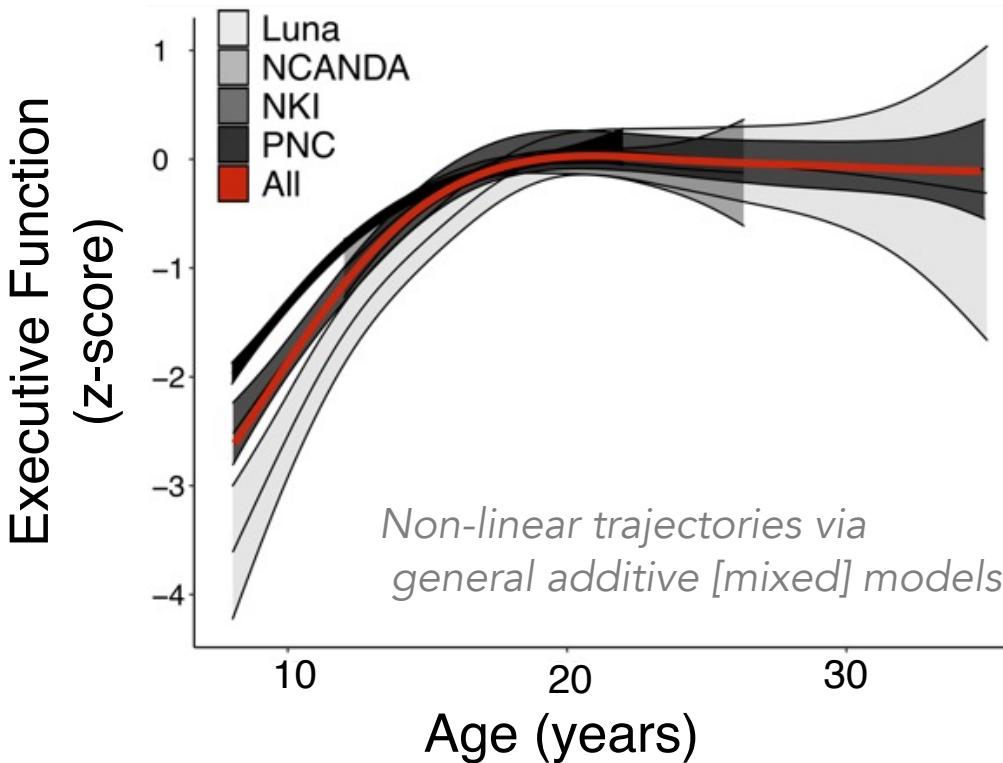


Reward Systems
- - -
Cognitive Systems
—

Shulman et al. 2016

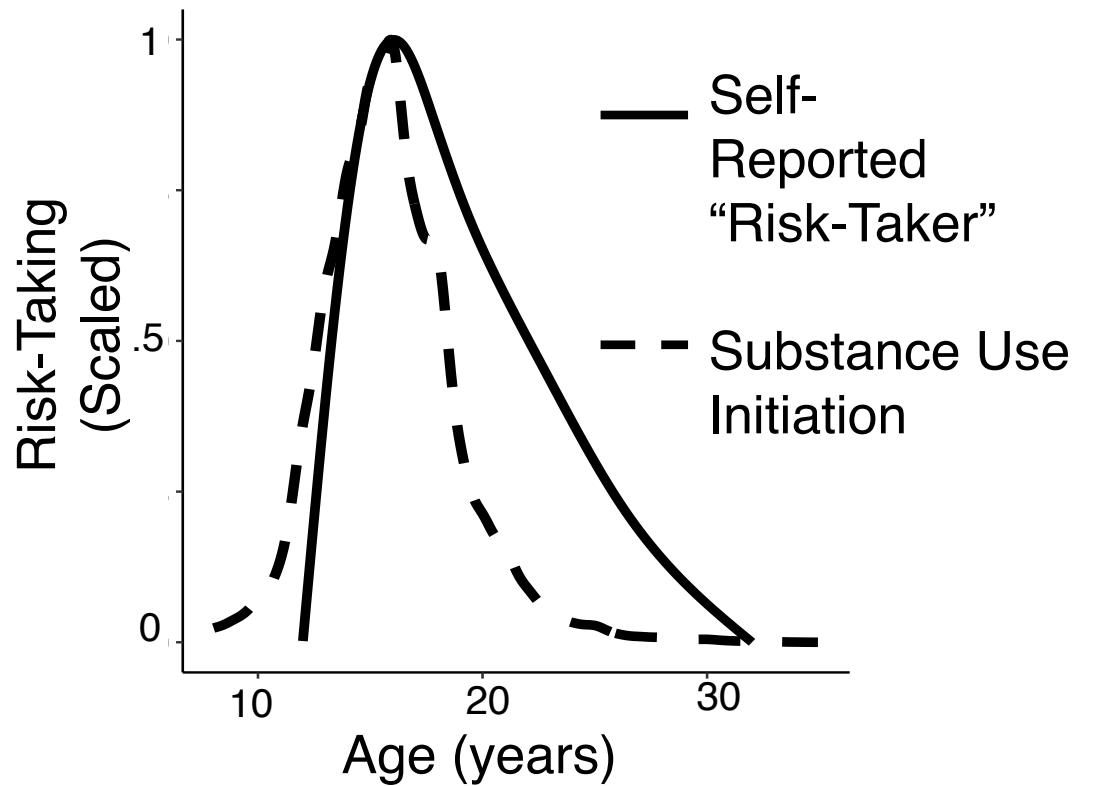
Adolescent Development

Cognition (Executive Function)
(N>10,000; 4 datasets; 17 EF measures)

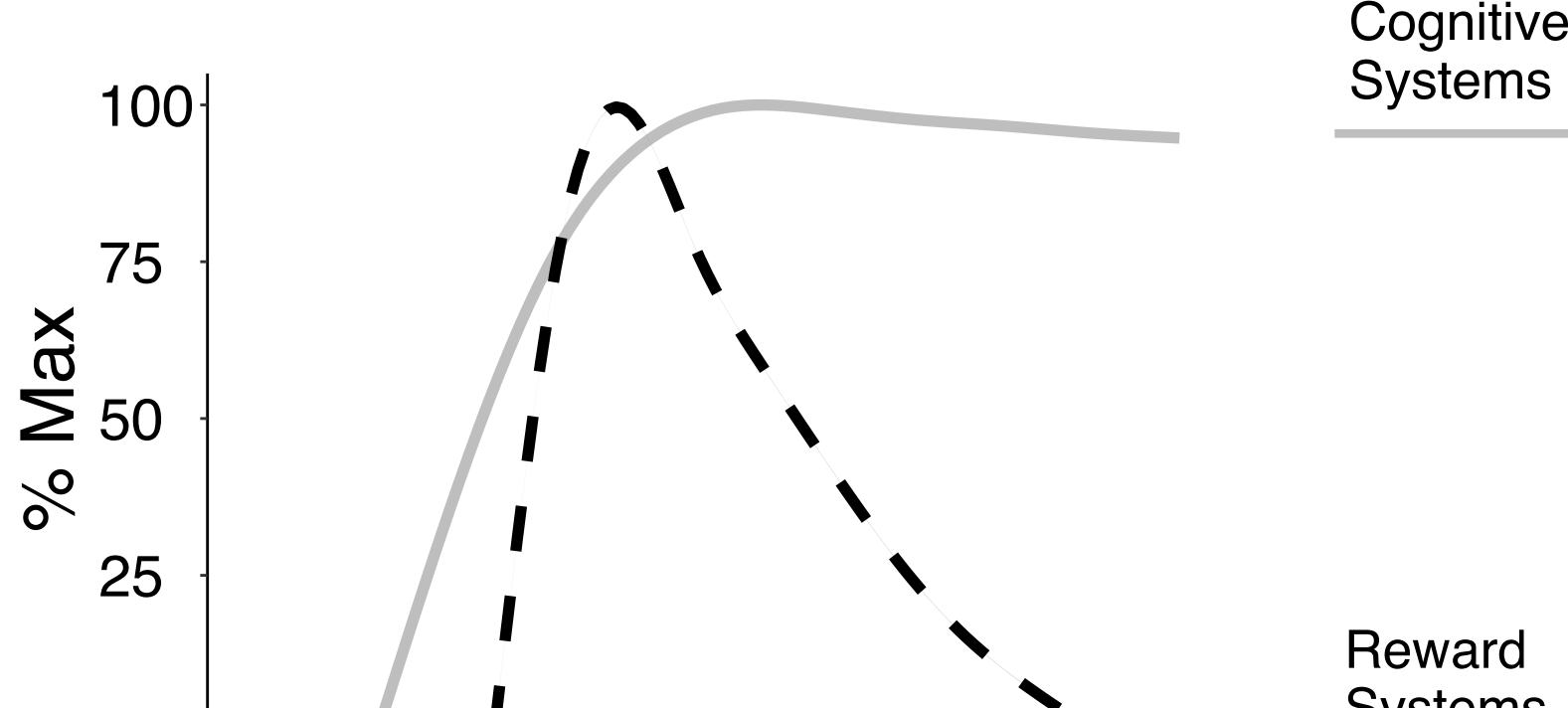


Adolescent Development

Reward (Risk-Taking)
($N > 1,000,000$; NSDUH 2002-2019)



Refined Developmental Model



Maturational Timing via Derivatives of Fits

Cognition

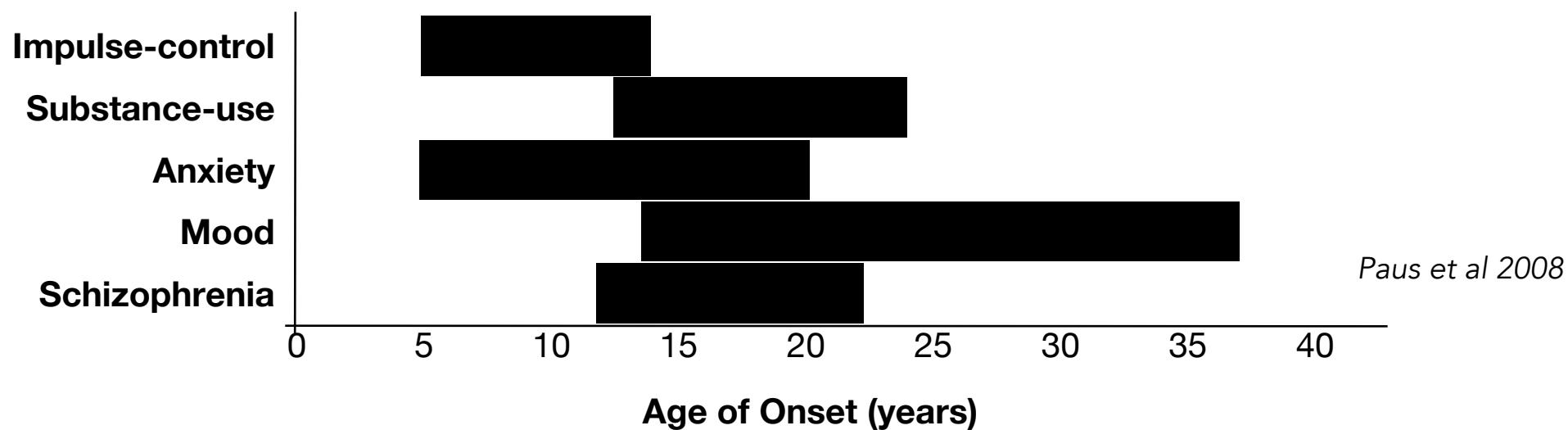


Reward

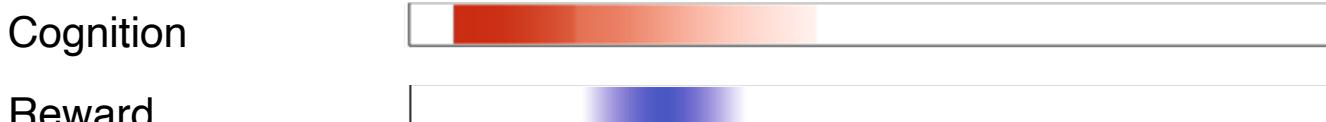


Refined Developmental Model

Mental Health/Substance Use Disorder Onset



Adolescent Maturational Timing



Tervo-Clemmens et al., 2023, 2024

Outline

Conceptual and methodological context for these questions.

Theories of human neurobehavioral development in adolescence

Non-linear modeling of lifespan trajectories

Foundational methods we have used to construct models across assessments and datasets.

R markdown and interactive examples

Extensions of these methods and looking forward to new directions.

Challenges to Reproducibility

Increasing concerns in psychology and neuroscience on the reproducibility of findings further limits clinical translation.

RESEARCH ARTICLE

Estimating the reproducibility of psychological science

Open Science Collaboration^{*,†}

Power failure: why small sample size undermines the reliability of neuroscience

[Katherine S. Button](#), [John P. A. Ioannidis](#), [Claire Mokrysz](#), [Brian A. Nosek](#), [Jonathan Flint](#), [Emma S. J. Robinson](#) & [Marcus R. Munafò](#) 

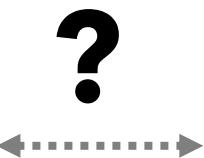
[Nature Reviews Neuroscience](#) **14**, 365–376 (2013) | [Cite this article](#)

Essay

Why Most Published Research Findings Are False

John P. A. Ioannidis

Clinical Intervention with Adolescents



Multi-assessment & Multi-dataset approach

Building generalizability and reproducibility into studies.

Investigations with relatively small datasets or narrow subsets of measures have identified general executive function development, but the specific maturational timing remains unknown.

It is unclear how these processes unfold, or their developmental similarity, among potential subprocesses indexed by the dozens of laboratory-based and neuropsychological executive function measures used in the broader literature.

Outline

Conceptual and methodological context for these questions.

Theories of human neurobehavioral development in adolescence

Non-linear modeling of lifespan trajectories

Foundational methods we have used to construct models across assessments and datasets.

R markdown and interactive examples

Extensions of these methods and looking forward to new directions.

Outline

Conceptual and methodological context for these questions.

Theories of human neurobehavioral development in adolescence

Non-linear modeling of lifespan trajectories

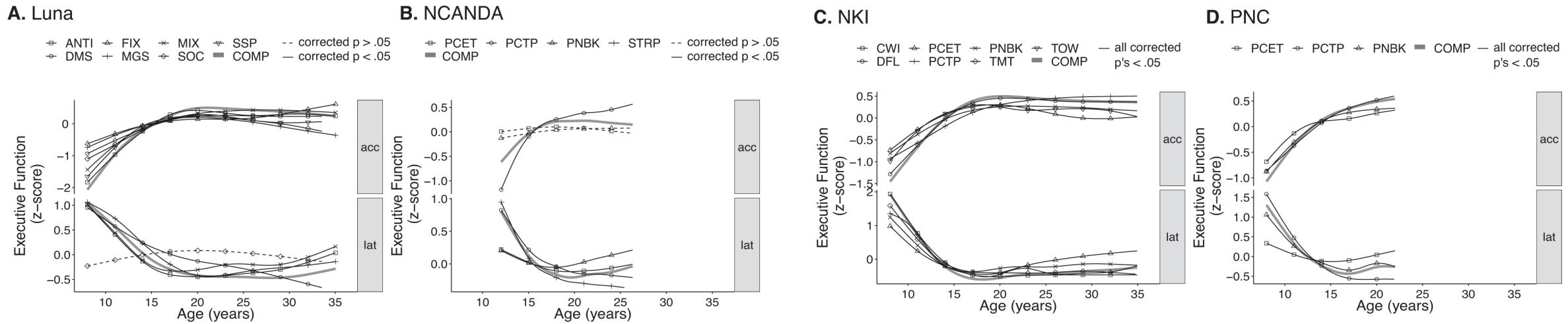
Foundational methods we have used to construct models across assessments and datasets.

R markdown and interactive examples

Extensions of these methods and looking forward to new directions.

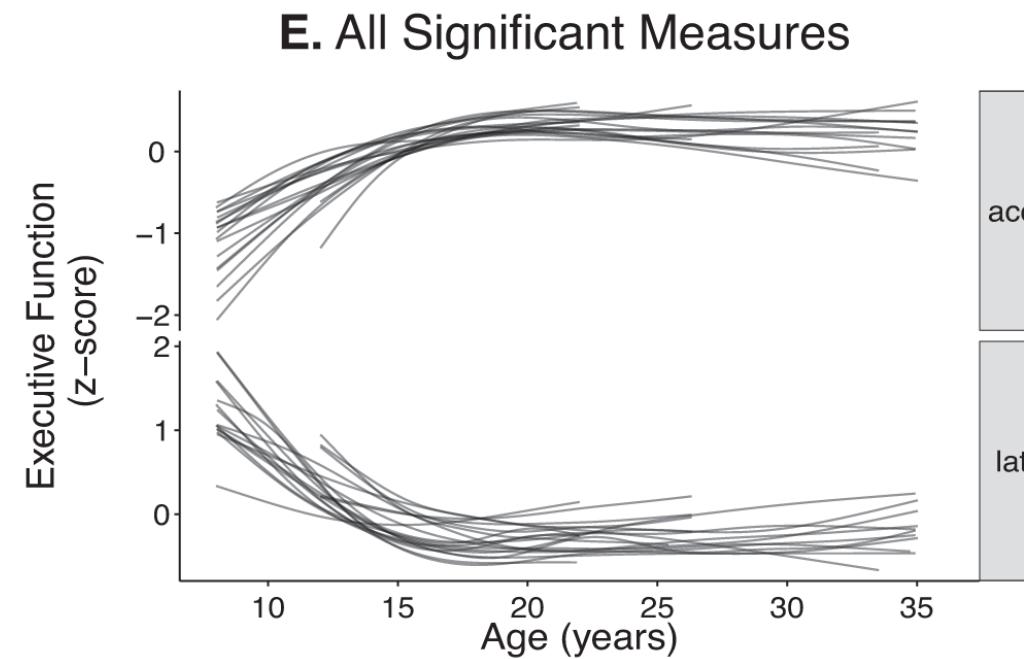
Review and extension of the “real” data

Four independent, publicly available adolescent to young adulthood datasets (Luna Cohort, NCANDA, NKI, PNC), total N = 10,766. Nearly all measures have corrected, age-related change.



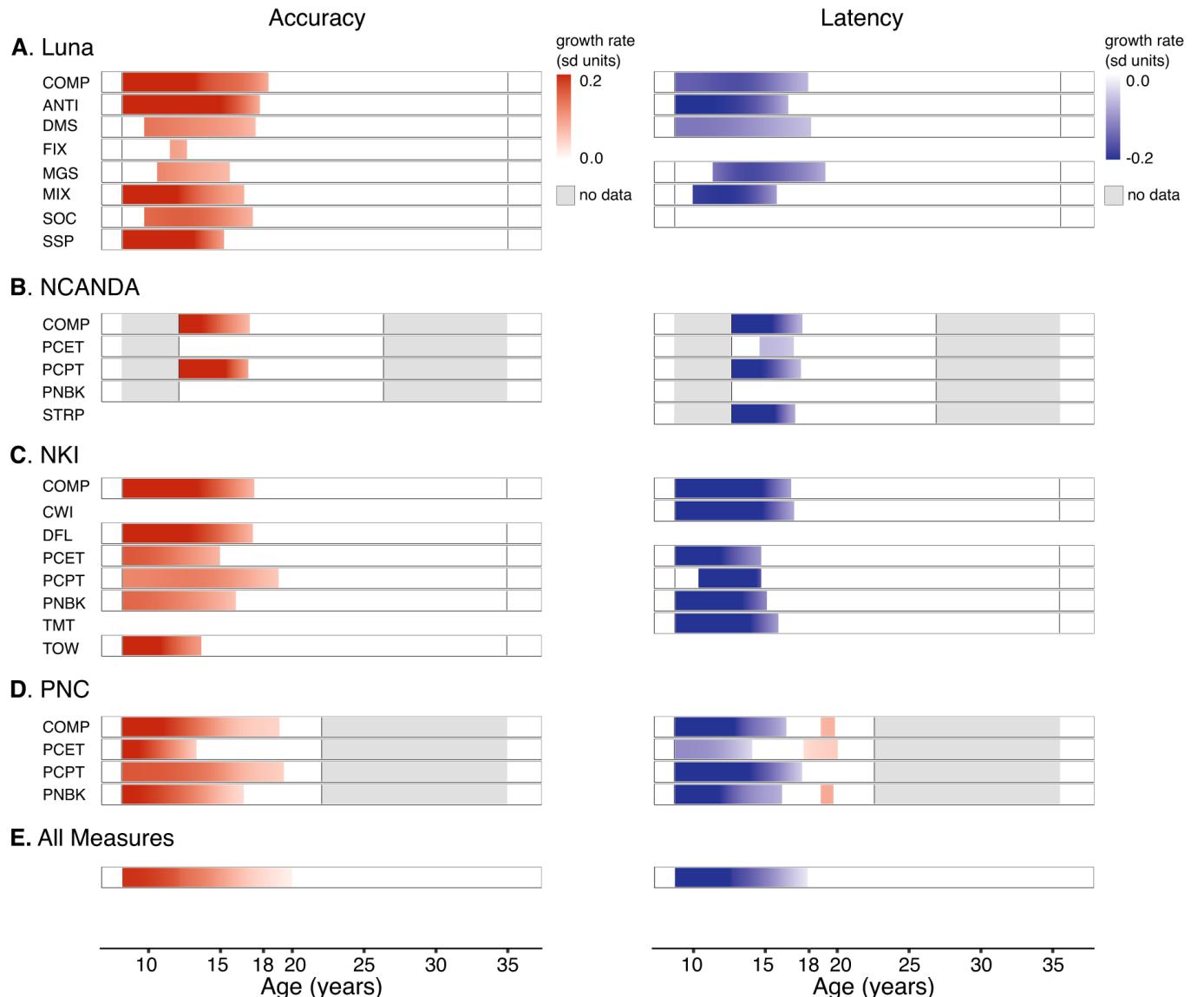
A Canonical Trajectory of EF Development

A common shape emerges clearly when we stack all significant measures on top of each other.



Consistency in timing via derivative testing

Testing of local age-related changes likewise supports developmental consistency across EF assessments.



Further Extensions: Aggregate inference

Point-wise meta-analysis of generalized additive models (as in Sørensen et al., 2021 *NeuroImage*).

Meta-analysis of generalized additive models in neuroimaging studies

Øystein Sørensen ^{a,*}, Andreas M. Brandmaier ^{d,e}, Dídac Macià ^c, Klaus Ebmeier ^f,
Paolo Ghisletta ^{g,h,i}, Rogier A. Kievit ^j, Athanasia M. Mowinckel ^a, Kristine B. Walhovd ^{a,b},
Rene Westerhausen ^a, Anders Fjell ^{a,b}

Highlights

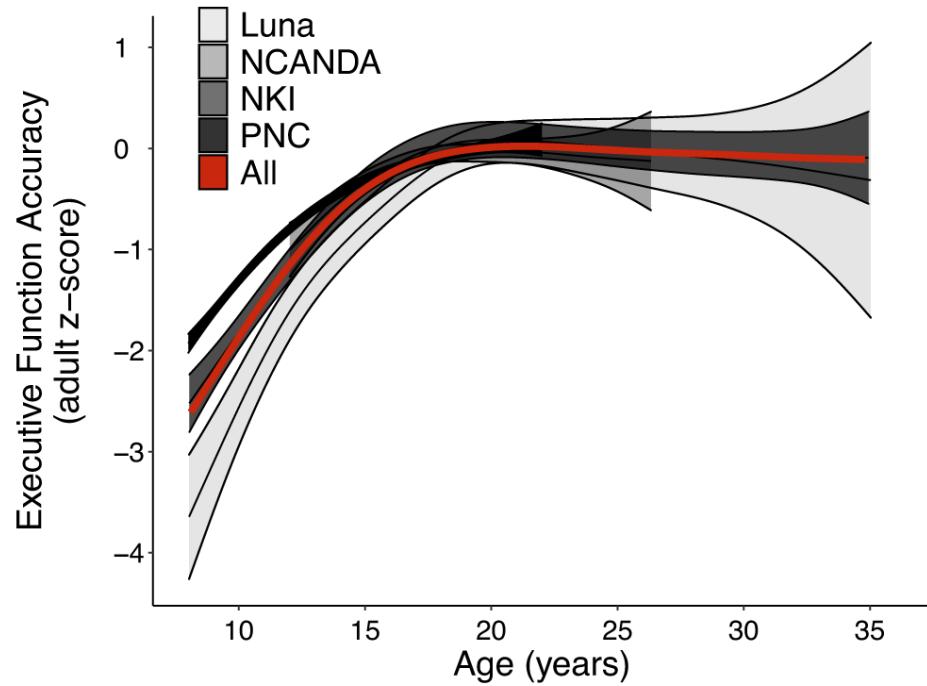
- Allows combination of nonlinear models without sharing data.
- Increases power and accuracy in neuroimaging studies.
- Illustrated in case study from the Lifebrain consortium.
- Is available in open source R package.

Further Extensions: Aggregate inference

Accuracy

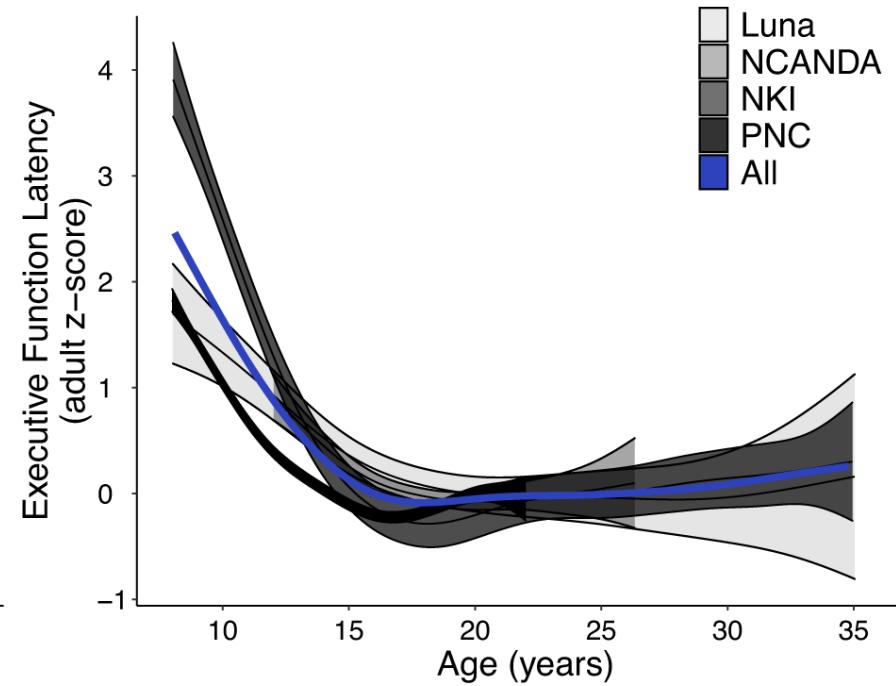
Age Effects Across Datasets

A.



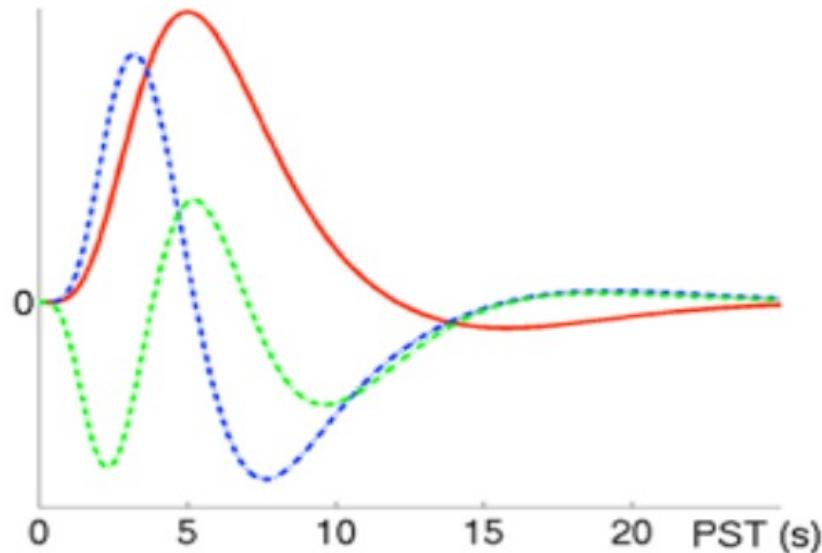
Latency

B.

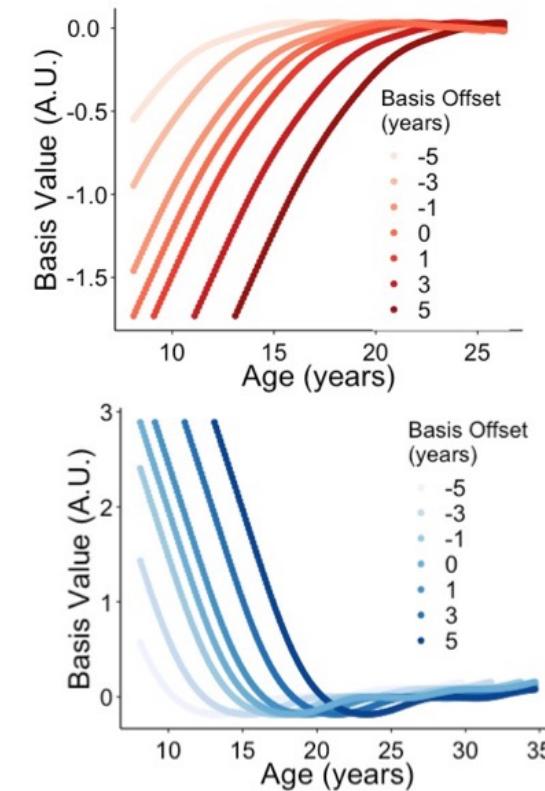


Further Extensions: Basis Functions

basis functions for task-based fMRI GLM



EF trajectory basis functions



Further Extensions

nature communications



Article

<https://doi.org/10.1038/s41467-023-42540-8>

A canonical trajectory of executive function maturation from adolescence to adulthood

Received: 27 January 2023

Accepted: 13 October 2023

Brenden Tervo-Clemmens ^{1,2,3}, Finnegan J. Calabro ^{4,5}, Ashley C. Parr ⁴, Jennifer Fedor ^{4,6}, William Foran ⁴ & Beatriz Luna ^{3,4,5}

Acknowledgements

**The Tervo-Clemmens (T-C) Lab
The Masonic Institute for the Developing Brain**



External Collaborators

Scott Marek, PhD, Washington University in St. Louis

Nico Dosenbach, MD, PhD, Washington University in St. Louis

Deanna Barch, PhD, Washington University in St. Louis

Wes Thompson, PhD, Laureate Institute for Brain Research

Henning Tiemeier, MD, PhD, Harvard

Leah Sommerville, PhD, Harvard

Beatriz Luna, PhD, University of Pittsburgh

Ashley Parr, PhD, University of Pittsburgh

Finnegan Calabro, PhD, University of Pittsburgh

Support



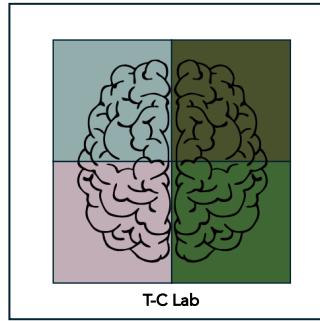
National Institute
on Drug Abuse



AMERICAN
PSYCHOLOGICAL
FOUNDATION



Participants and their families!



Modeling Adolescent Executive Function Development Across Assessments and Datasets

Brenden Tervo-Clemmens, PhD

University of Minnesota

btervocl@umn.edu



@tervoclemmensb