Making movies of the brain's electrical potentials: A practical procedure for dynamic source localization analysis with validating simulation

Matthew F. Kirby[1,2], Rogelio Gutierrez-Sampson[1,3], Dao A.T. Pham[1,4], Gary Goldfield[5], Amedeo D'Angiulli[1,3*]

[1]NICER Lab, Carleton University, Ottawa, ON, Canada; [2]Department of Psychology, CITY College, University of York Europe Campus, Thessaloniki, Greece;
[3]Department of Neuroscience, Carleton University, Ottawa, ON, Canada; [4]Department of Computer and Electrical Engineering, Carleton University, Ottawa, ON;
[5]Children's Hospital of Eastern Ontario, Ottawa, ON, Canada; *amedeo.dangiulli@carleton.ca

INTRODUCTION

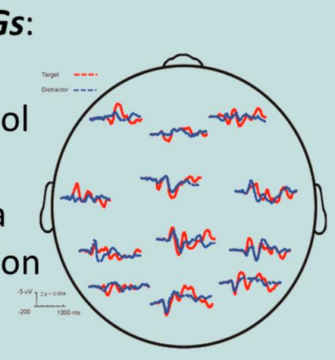
- Event-related potentials (ERPs) average time-locked data taken from multiple electroencephalogram (EEG) trials, thereby allowing analysis of a specific electrophysiology process within a certain time window. [1]
- Despite their high temporal resolution, ERPs offer poor spatial resolution which leads to difficulties in localizing latent neural generators, an issue commonly known as the "inverse problem." [2]
- Dipole source localization analysis (DSLA) yields solutions for the inverse problem and can supplement ERP findings with anatomical details. [3]
- DSLA may result in underqualified data when studying a large area of the brain, or with an unpredictable number of active regions occurring at different times. [4,5]

OBJECTIVES

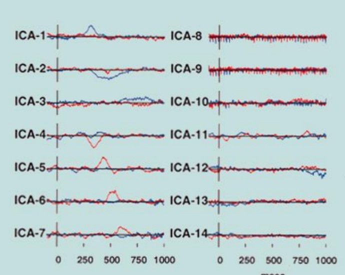
- Determine a practical procedure which may permit to narrow down DSLA within the most relevant time windows and test their validity through simulation.
- Use this novel procedure, called *dynamically-guided dipole source localization analysis*, to appropriate pre-existing tools for the purpose of accurately examining and analyzing the neurofunction of distinct demographic groups despite limited MRI data and normalized templates.

MATERIALS AND METHODS

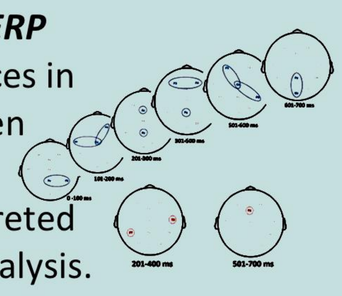
Step 1 – *ERPs from EEGs*: Reprocessed ERP data collected from preschool children (n=26, mean age=4.12) performing a visual sustained attention task with target and distractor stimuli.



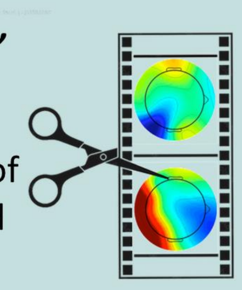
Step 2 – *Independent Components Analysis*: ERP components were identified using the EEGLAB FASTICA algorithm.



Step 3 – *Identify Max ERP Activity Path*: Differences in ERP waveforms between target and distractor conditions were interpreted via ERP activity path analysis.

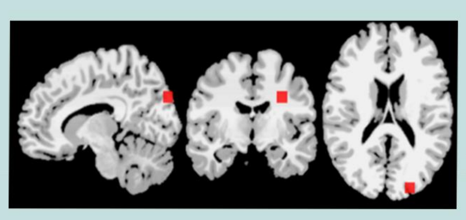


Step 4 – *Topographical Maps, Movie Review & Snipping*: Topographic maps were created to represent epochs of averaged ERPs and assembled as movie clips.

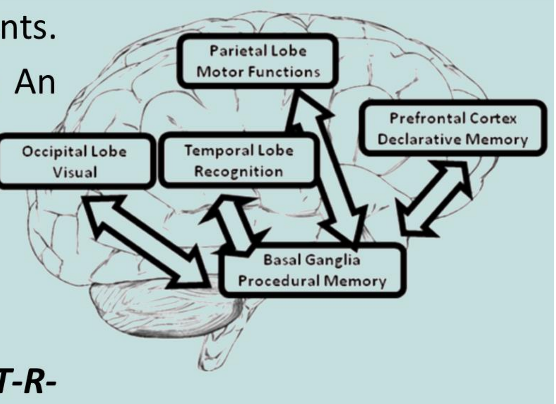


Step 5 – *Topographical Maps, Standstill*: Maps were selected for further analysis.

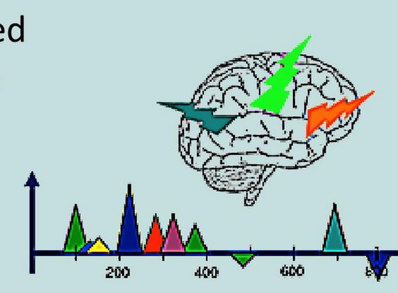
Step 6 – *Dipole Analysis, Talairach Labelling*: The DIPFIT component of EEGLAB was used to estimate a set of dipoles in the averaged ERP data that would explain the independent components.



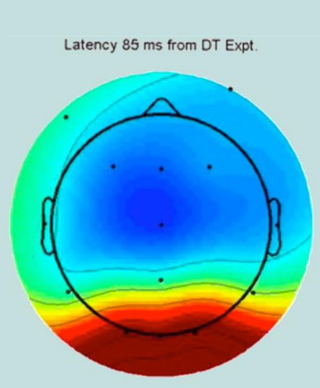
Step 7 – *ACT-R Model*: An adapted version of Adaptive Control of Thought-Rational was used to model and simulate data.



Step 8 – *Simulated ACT-R-based Spike-series*: Simulated electrical activity in the brain using the neurocognitive model. Calculated the resulting electric field at the surface of the head for each electrode.



Step 9 – *Simulation of ERP Topographical Maps, Standstills*: Simulated electrical activity in the brain using the neurocognitive model and calculated the resulting voltage at each electrode. Simulated maps were created by converting the ACT-R spike-series into a relative voltage scale (with range from blue/black, -6µV, to red/orange, 6µV).



Final Step – *Validation Test*: Compare the ERP activity of real and simulated sources.

RESULTS

- Regression analysis between the actual child data (Fig.A) and the dynamically-guided DSLA simulation data (Fig.B) showed high fit, $R^2 > 0.97$ ($p < 0.005$), with the exception of the data at 695ms ($R^2 = 0.40$; $p = 0.47$).
- Comparison with the "static" DSLA simulated adult data (Fig.C) revealed that dynamically-guided DSLA modelling and simulation produced a higher fit with the actual child data. This comparison shows large differences in the timing attributed by ACT-R to the same sources under the two DSLA approaches, indicating important deviation from homology in the putative sequence of neural processes.

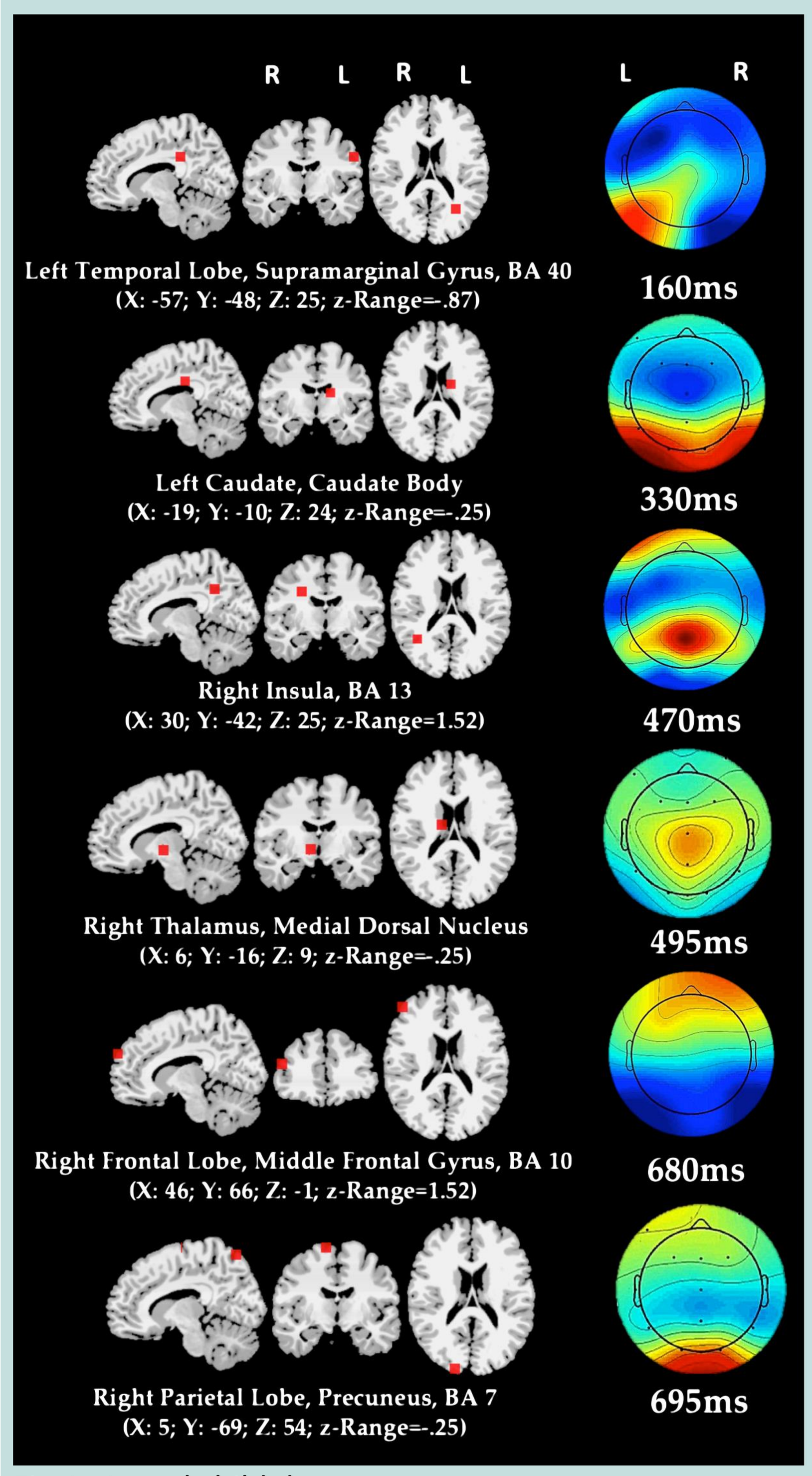


Fig.A: Actual child data

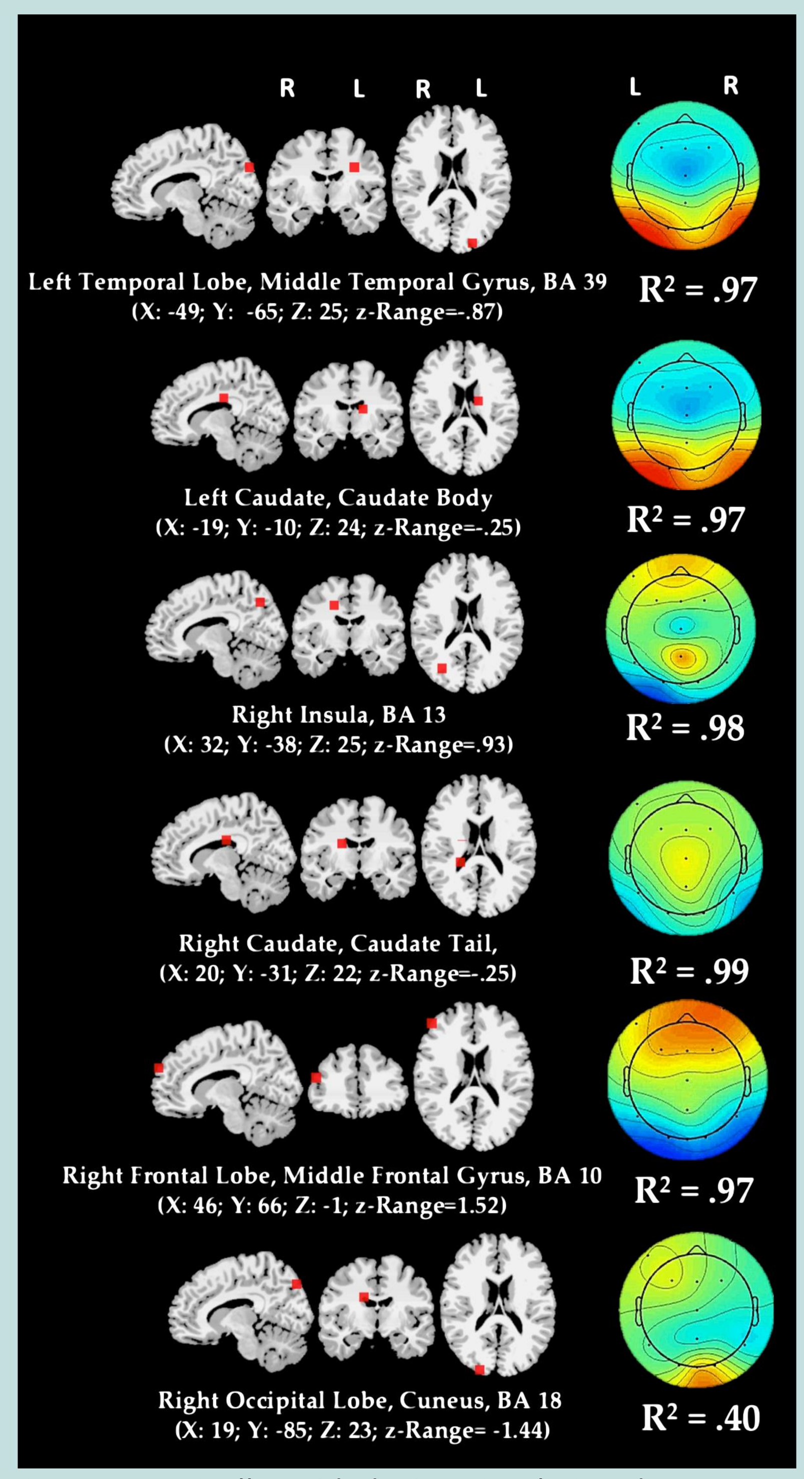


Fig.B: Dynamically-guided DSLA simulation data

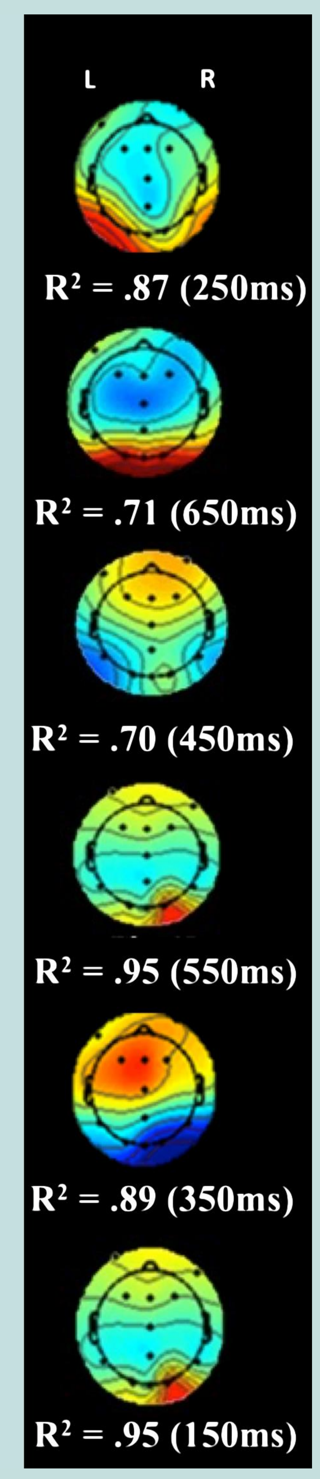


Fig.C: "Static" DSLA adult simulation data

CONCLUSIONS

- These findings demonstrate that readily available modeling and simulation tools can be appropriated to reliably fit the neural responses and corresponding behaviours of an under-studied demographic sample.
- It may be possible to employ dynamically-guided DSLA as a method to identify structural and functional similarities within and between populations, this could have a variety of applications across multiple disciplines, which include: examining specific characteristic biomarkers of neurodevelopmental disorders, informing and evaluating the effectiveness of specific interventions, investigating the efficacy of educational strategies, and more.
- The specific components employed by this iteration of dynamically-guided DSLA can be replaced by more powerful and accurate techniques as they become available, while the analytical framework and objective of producing comparable visualizations of neural activity in a studied demographic and a simulation model remain unchanged.
- The modular nature of dynamically-guided DSLA is what makes it a particularly suitable technique in a field of study where rapid technological progress is the expected norm, and it affords many opportunities for future research and development into its application as a valuable process of examining neurofunction.

REFERENCES

1. Rugg, M., & Coles, M. (1995). Electrophysiology of mind event-related brain potentials and cognition. Oxford University Press.
2. Sanei, S.; Chambers, J.A. EEG Signal Processing; 1st ed.; Wiley-Interscience: Chichester, West Sussex, UK, 2007.
3. Bathelt, J.; O'Reilly, H.; de Haan, M. Cortical Source Analysis of High-Density EEG Recordings in Children. J. Vis. Exp. 2014, e51705, doi:10.3791/51705.
4. Darvas, F., Pantazis, D., Kucukaltun-Yildirim, E., & Leahy, R. (2004). Mapping human brain function with MEG and EEG: methods and validation. Neuroimage, 23, S289–S299. https://doi.org/10.1016/j.neuroimage.2004.07.014
5. Hämäläinen, M., & Ilmoniemi, R. (1994). Interpreting magnetic fields of the brain: minimum norm estimates. Medical & Biological Engineering & Computing, 32(1), 35–42. https://doi.org/10.1007/BF02512476

DRDC RDDC
THALES CANADA
Défense nationale National Defence
NSERC CRSNG