Rapid Automatized Naming (RAN) Linked to EEG Functional Network Integration during Single-Word Reading

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Purpose

Exploratory study of fluent word reading relating functional neural integration (theta EEG) during word and word-like processing to RAN skills (behavior).

Previous research suggests that RAN skills may be related to how information is transferred amongst cortical regions functionally specialized for the visual and (pre)lexical processing that occurs ~ 300ms after seeing a word.[1] This 'visual-lexical integration' is thought to depend on a hub region in the left ventral occipitotemporal cortex (LvOT).[2]

Dynamic EEG phase synchronization can index interactions amongst cortical regions as they unfold during word reading. Theta synchrony is a neural mechanism fundamental for this integration.[3,4] Here, we explore how individual differences in theta synchronization of LvOT during word reading is associated with RAN.

Method

Participants (right-handed, typically developing)
72 children (grade 3-5; M=10.01); **24 adults** (college; M=20.33)

EEG Recording Stimuli/Task

- **Words** (tree)
- **Pseudowords** (braff)
- **Letter-Strings** (fbrfa)
- **False-Fonts**

Animal name targets in a semantic categorization task. 500ms presentation children; 350ms adults.[5]

Reading Measures

RAN-Letters, RAN-Numbers[6]

Analyses

EEG Pre-processing: Ocular components (ICA) and trials with > |250 µV| over 200ms (within -2 to 2s) removed. *N*-trials: children = 52.1 (SD = 5.4); adults = 56.2 (SD = 3.69).

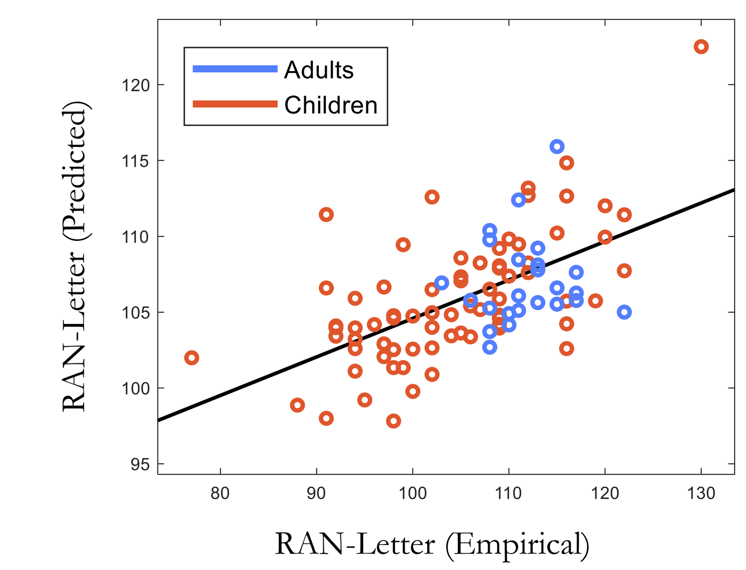
Connectivity: Trials *Z*-scored, Filtered (4-7Hz), instantaneous phase calculated with Hilbert transform. Phase-lag index (**PLI**): 0-1; asymmetry of phase-differences across trials.

LASSO Regression: *L1* norm of β's penalized by factor of λ (selected through 12-fold cross-validation). **Inputs:** Theta integration within/between left, right, and posterior regions (200-400ms, 24 total). **Outputs:** RAN-Letters, RAN-Numbers (separate models).

Research Questions

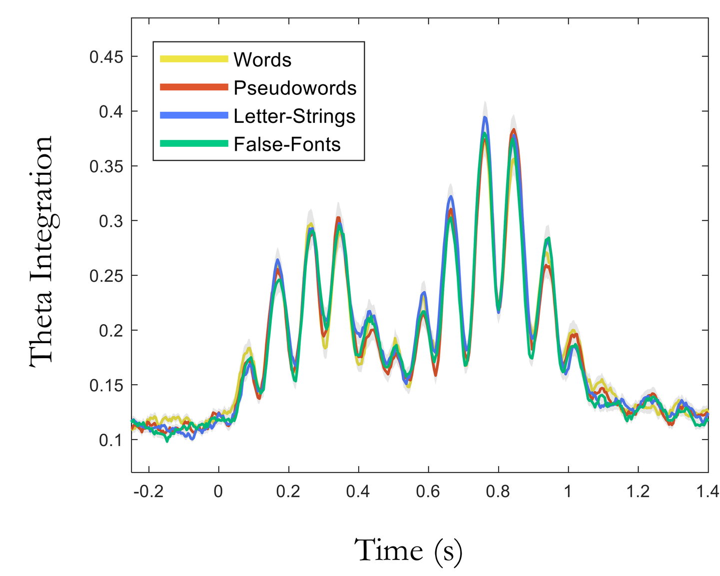
Does **theta integration** [mean phase-lag index (PLI) across trials in 4-7Hz EEG signal from 200-400ms during the processing of words and word-like stimuli…

1) Predict rapid automatized naming (RAN) scores?
2) Differ between conditions (words vs. word-like stimuli) or groups (adults vs. children)?
3) Differ as a function of RAN scores?
4) Show an association with RAN-Letters scores after controlling for RAN-Numbers scores?



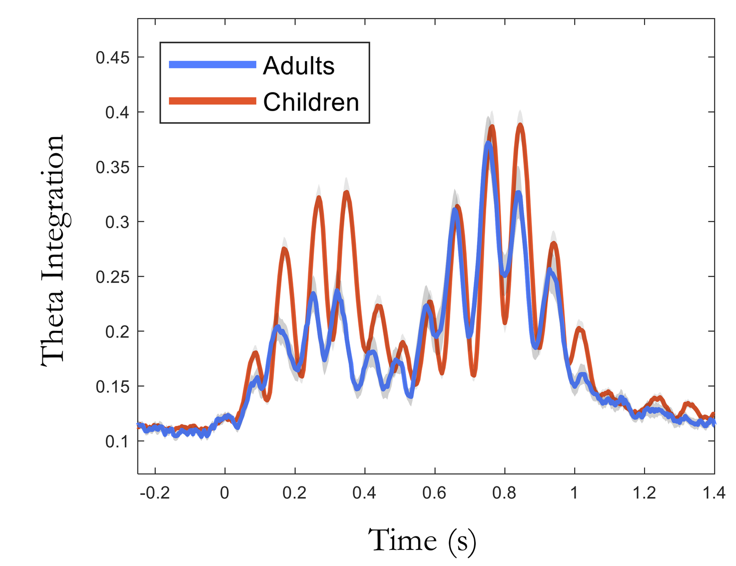
1) Theta integration predicts RAN

LASSO regression: **RAN-Letters** (out-of-sample $R^2 = .08$; $R^2 = .35$; shown above) and **RAN-Numbers** (out-of-sample $R^2 = .02$; $R^2 = .24$) scores were predicted. Highest β: left occipitotemporal (T5, TO1, O1, P3) and left temporocentral (T3, C5, C4, CT5) integration.



2a) Theta integration does not differ between conditions

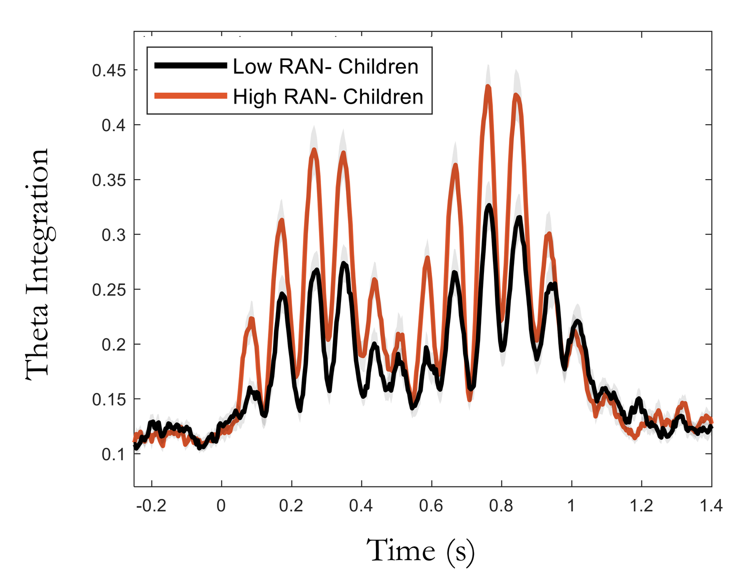
Mixed-model ANOVA: $p > .1$
Average waveforms across children and adults shown above (gray: SE)



2b) Theta integration differs by group (children > adults)

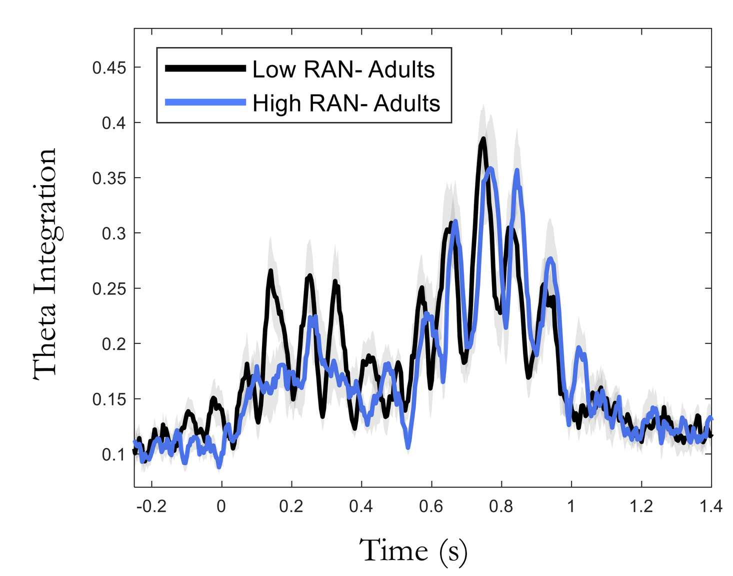
Mixed-model ANOVA: $p < .0001$
Average waveforms across all stimuli shown above (gray: SE)

3) Theta integration differs as a function of RAN scores in children, but not adults



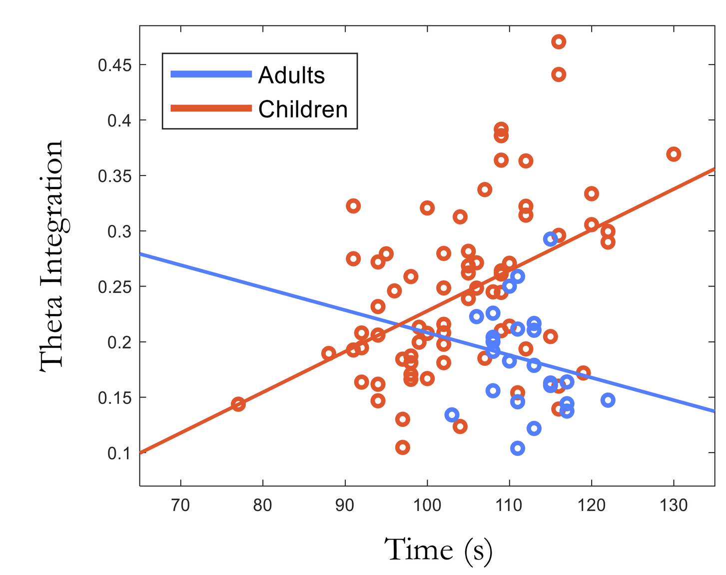
Increased theta integration in children with high vs. low RAN scores

Shown above: theta integration in response to **Words** for **children** with high and low **RAN-Letters** scores (median split; $n = 36$ each)



No significant theta integration difference in adults with high vs. low RAN scores

Shown above: theta integration in response to **Words** for **adults** with high and low **RAN-Letters** scores (median split; $n = 12$ each)



Shown above: correlation between theta integration in response to **Words** and **RAN-Letters** scores is significant in **children** ($r = .46$, $p < .0001$, red) but not **adults** ($r = -.18$, $p > .1$, blue).

4) Theta integration is associated with RAN-Letters in children, even after controlling for RAN-Numbers

Children

Feature	Pearson's R RAN-Letters	Partial Correlation Controlling RAN-Numbers	OLS Regression β
Words	**.46*** **	**.32***	**6.73*** **
Pseudowords	**.27***	.21	.81
Letter-Strings	.20	.15	-.95
False-Fonts	.19	.23	-3.11

***$p < .001$
**$p < .01$
*$p < .05$

Adults

Feature	Pearson's R RAN-Letters	Partial Correlation Controlling RAN-Numbers	OLS Regression β
Words	-.18	-.29	-0.98
Pseudowords	-.15	.05	0.50
Letter-Strings	-.35	-.29	-2.80
False-Fonts	-.11	-.25	1.2

Summary

Children with faster RAN-Letters scores show stronger theta integration between left occipitotemporal and temporocentral regions from 200-400ms, particularly for words.

Conclusions

1) Synchronized theta oscillations between LvOT and left temporocentral regions appears to integrate visual/pre-lexical information and may be a neural correlate of RAN in children.

2) Although there were no significant differences among stimulus conditions overall, considering RAN-Letters scores revealed a trend for specificity to real words in children. During development, faster letter processing may be accompanied by a specialization of theta integration.

3) Theta integration was maximal in children with high RAN-Letters scores (higher than both children with low RAN-Letters scores and adults). This pattern may be consistent with the U-shaped development of integration for LvOT function predicted by the interactive account.[2]

4) Significant association with RAN-Letters when controlling for RAN-Numbers suggests that theta integration in this context is not related to general processing speed. Rather, it may be specialized for letter processing, particularly letter processing in words.

References

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