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Inter-channel Granger Causality for Estimating EEG Phase Connectivity Patterns in Dyslexia

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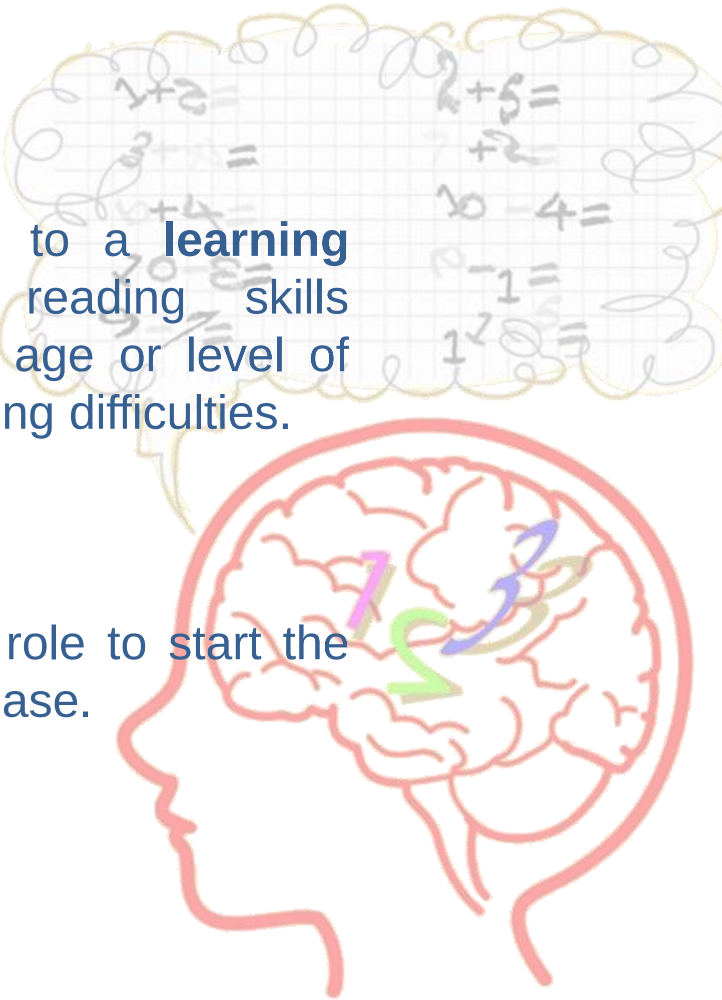
Presentation Outline

Introduction



- **Developmental dyslexia** (DD) refers to a **learning difficulty** that hampers learners' reading skills acquisition irrespective of their mental age or level of schooling. It results in reading and learning difficulties.

- **A precise diagnosis** plays a decisive role to start the treatment in the **early stages** of the disease.

Introduction

- Newly models are pointing to **atypical dominant neural entrainment** for three main rhythm stimuli categories:
  - Slow rhythmic **prosodic** (0.5–1 Hz)
  - **Syllabic** (4–8 Hz)
  - **Phoneme** (12–40 Hz)

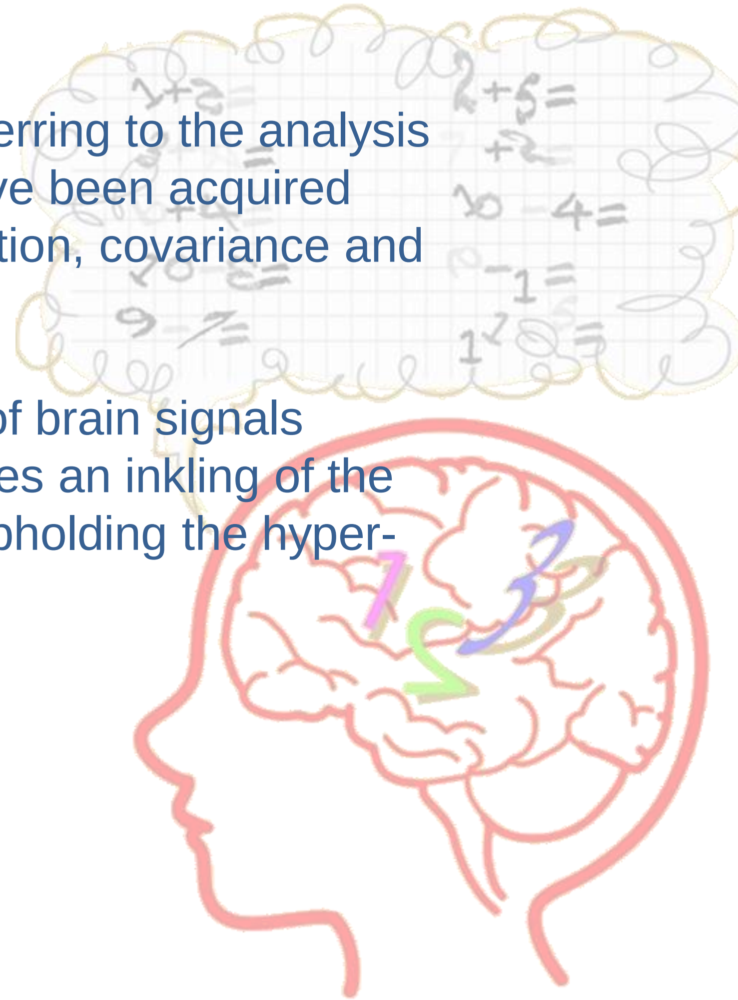
- Learners with DD perform **atypical oscillatory sampling using at least one temporal rate**, introducing phonological difficulties in the comprehension of certain linguistic units, e.g. phrases, phonemes or syllables.

- **Not all EEG frequency bands** (i.e. Delta, Theta, Alpha, Beta, and Gamma) **equally experience this phenomenon** of atypical neural connectivity.

Introduction

- We focus in **connectivity analysis**, referring to the analysis of measures linking two signals that have been acquired through separate channels, e.g. correlation, covariance and causality.

- Using these parameters in the context of brain signals emanating from different regions provides an inkling of the **underlying neural network**, thereby upholding the hyper-connected model of the brain.



Our hypothesis

Impaired neural oscillatory tracking of **slow amplitude modulation patterns** is one plausible **source of impaired rhythm** tracking in dyslexia.

The AM-based measure **revealed atypical rhythmic entrainment** by dyslexic participants to prosodic/syllable patterns in speech.

Previous research support the view that rhythmic entrainment at **slow (<5 Hz) rates** is atypical in dyslexia. (https://doi.org/10.1016/j.heares.2013.07.015)

Our hypothesis

Estimating **channels' connectivity** involves the analysis of these **channels' phases**.

The statistical hypothesis test known as the **Granger causality** test reveals whether **a time series is a factor**, thereby helping to predict the characteristics of further time series.

Granger causality **matrices** establish **sufficient patterns to classify** the subjects.

Methodology

Data

- We utilized **EEG data** from the University of Málaga's Leeduca Study Group. **97 participants**.

67 skilled readers + 30 dyslexic readers

Auditory stimuli in a 15-min session → We focused on the modulated stimulus at prosodic frequency

Methodology

Preprocessing

- **Independent component analysis**.
- **Removing artefacts**.
- **Filtering** in the five EEG frequency bands.

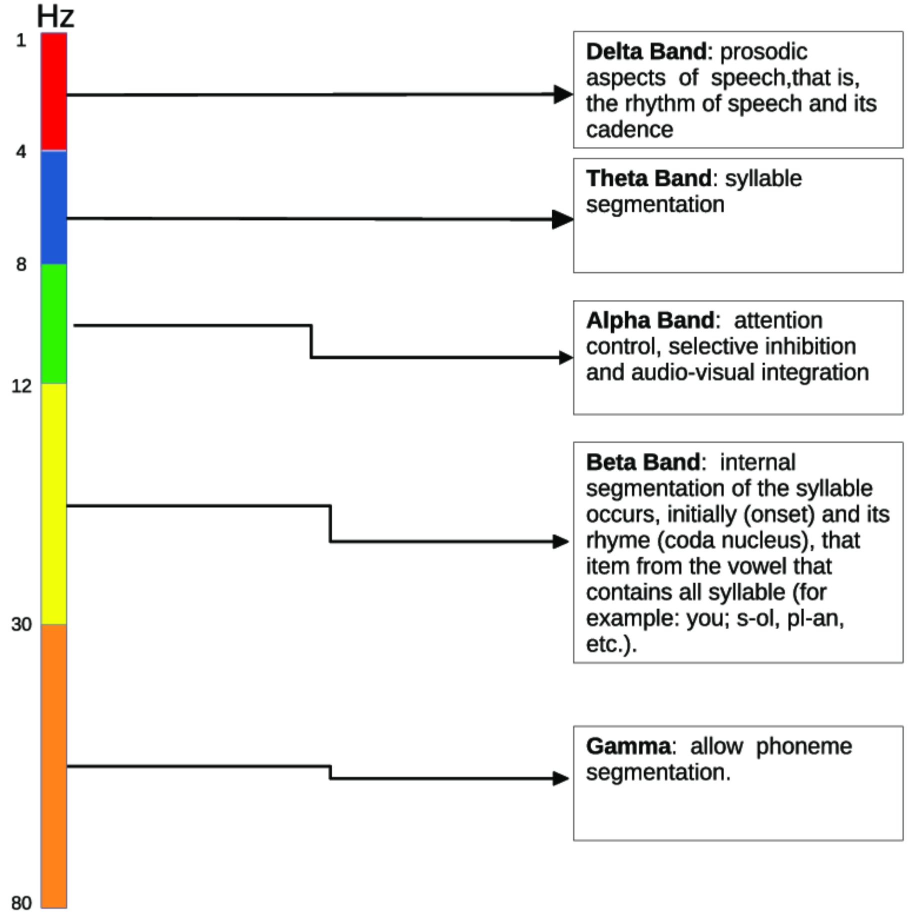


Figure from https://doi.org/10.3390/s21217061

Methodology

- **Hilbert Transform**

$$\mathcal{H}\left[x(t)\right] = \frac{1}{\pi}\int_{-\infty}^{+\infty} \frac{x(t)}{t-\tau} d\tau$$

- **Analytic signal $z_i(t)$**

$$z_i\left(t\right) = x_i\left(t\right) + j\mathcal{H}x_i\left(t\right) = a(t)e^{(}j\phi(t))$$

- **Instantaneous, unwrapped phase**

$$\phi\left(t\right) = tan^{-1}\frac{im\left(z_i\left(t\right)\right)}{re\left(z_i\left(t\right)\right)}$$

Methodology

- **Granger Causality Test**

It fundamentally asserts that "**the past and present may cause the future, but the future cannot cause the past**".

$$\widehat{y_t}_1 = \sum_{k=1}^{l} a_k y_{t-k} + \varepsilon_t$$

$$\widehat{y_t}_2 = \sum_{k=1}^{l} a_k y_{t-k} + \sum_{k=1}^{w} b_k x_{t-k} + \eta_t$$

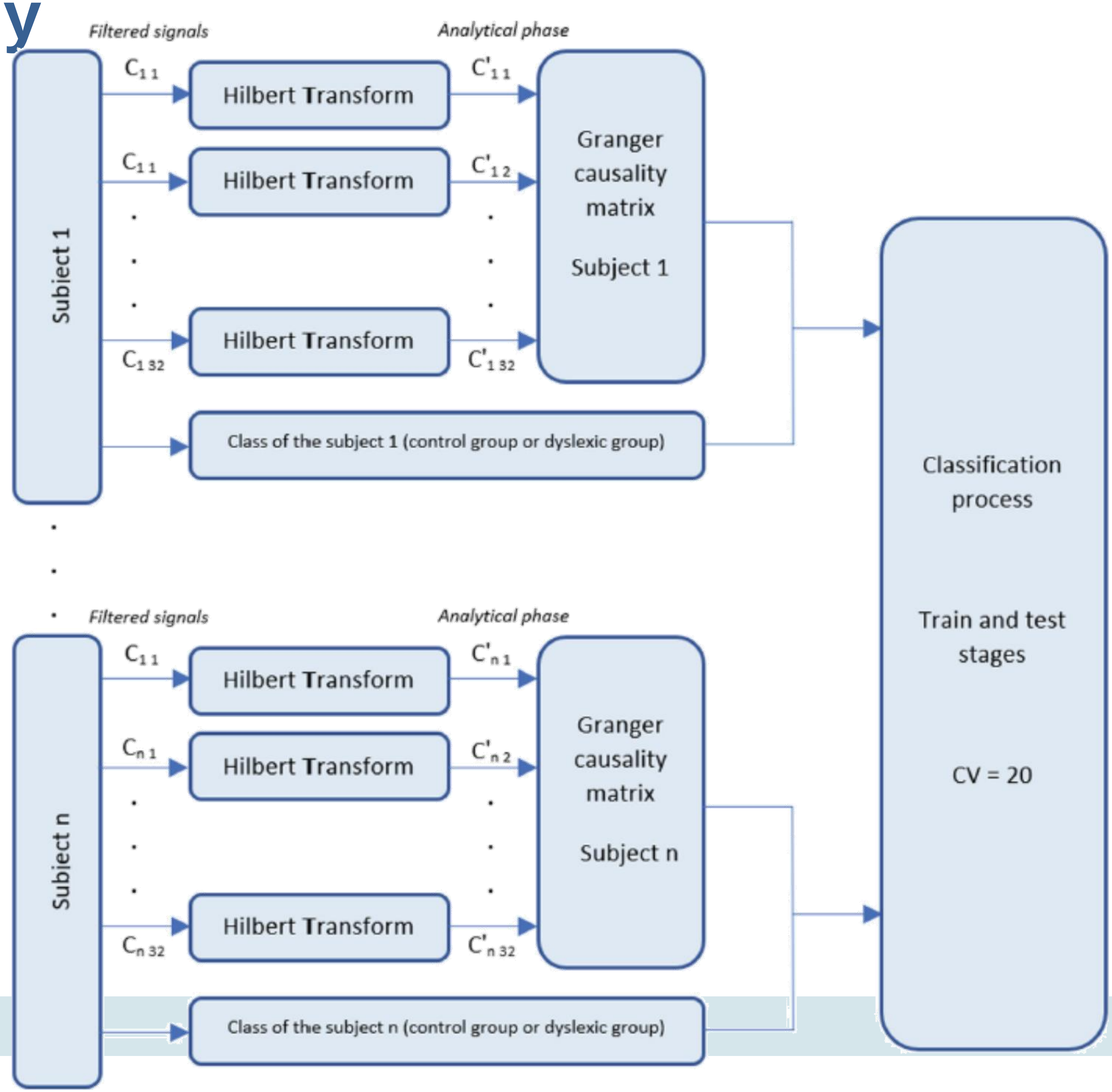
Methodology

➢ **Machine Learning Classification**

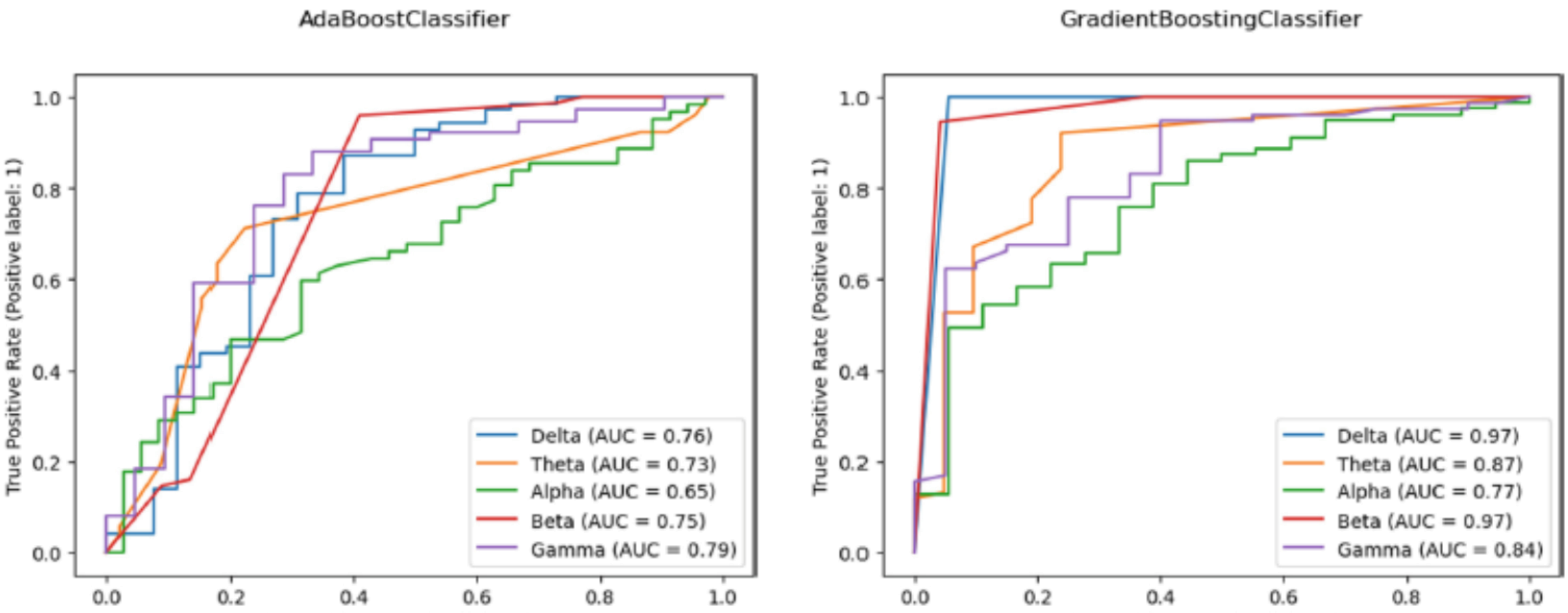
We used **cross-validation** method with 20 folds and a parameters grid (GridSearchCV library).

Algorithm	Parameter	Range
Ada Boost	n_estimators	1 to 25
	Learning rate	1 to 3.5
	Boosting algorithm	SAMME, SAMME.R
Gradient Boosting	N_estimators	1 to 10
	Loss	deviance, exponential
	Learning rate	0.05 to 0.5
	Criterion	friedman_mse, squared_error, mse, mae
	Min_samples_split	0.1 to 3
	Min_samples_leaf	0.1 to 3
	Max_depth	1 to 4

Methodology



Results


AdaBoostClassifier
True Positive Rate (Positive label: 1)
Delta (AUC = 0.76)
Theta (AUC = 0.73)
Alpha (AUC = 0.65)
Beta (AUC = 0.75)
Gamma (AUC = 0.79)
GradientBoostingClassifier
True Positive Rate (Positive label: 1)
Delta (AUC = 0.97)
Theta (AUC = 0.87)
Alpha (AUC = 0.77)
Beta (AUC = 0.97)
Gamma (AUC = 0.84)

Results

Algorithm	Band	Accuracy	Precision	Recall	AUC
Ada Boost	Delta	0.75 ± 0.16	0.86 ± 0.15	0.85 ± 0.16	0.76
	Theta	0.61 ± 0.26	0.83 ± 0.12	0.62 ± 0.29	0.73
	Alpha	0.61 ± 0.17	0.83 ± 0.14	0.68 ± 0.21	0.65
	Beta	0.77 ± 0.15	0.84 ± 0.14	0.89 ± 0.18	0.75
	Gamma	0.78 ± 0.18	0.91 ± 0.09	0.90 ± 0.17	0.79
Gradient Boost	Delta	0.77 ± 0.19	0.80 ± 0.17	0.91 ± 0.14	0.97
	Theta	0.70 ± 0.22	0.80 ± 0.15	0.87 ± 0.22	0.87
	Alpha	0.73 ± 0.16	0.85 ± 0.13	0.89 ± 0.14	0.77
	Beta	0.79 ± 0.17	0.84 ± 0.14	0.89 ± 0.19	0.97
	Gamma	0.74 ± 0.17	0.90 ± 0.11	0.89 ± 0.17	0.84

Conclusions and future work

- The **causality matrices** between channels **allow the classification** of subjects with and without DD.
- This implies that the **interconnection** of the different zones **is not the same** in subjects with DD.
- The **delta band** seems to be where these differences are most accentuated, and allows a clearer classification. Thus, a **precision of 0.77 and AUC of 0.97** are achieved using the **Gradient Boosting** classifier.
- However, the performance ratios are also **acceptable** in the **beta and gamma bands**, which indicates that at these frequencies a different **interconnection** of the brain areas is also taking place.
- It is noteworthy that the results are **consistent** with the **two classifiers** used.

Conclusions and future work

- As **future work**, we intend to test the validity of the proposed method with **two other stimuli**, corresponding to **syllabic** and **phoneme** levels.

Thanks