

Development of an EEG-neurofeedback to boost Interhemispheric Connectivity during Phonological processing: Validation in a Pediatric Population

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Introduction

Developmental dyslexia (DD) is characterised by struggles in phonological representations of speech sounds. Phonological processing is strongly left-lateralized, particularly in left temporoparietal areas, and research reports reduced or disrupted left-hemisphere (LH) activation in DD. To compensate for this reduced LH engagement, children with DD increasingly recruit preserved right-hemisphere (RH) systems. However, this RH overactivation may only be beneficial and compensatory if information is successfully transferred to support the LH via interhemispheric (IH) connectivity through the corpus callosum. Studies have reported weaker callosal integration in DD, suggesting that reduced connectivity may prevent preserved RH systems from effectively supporting the dysfunctional LH phonological network^{^1}. We hypothesise that boosting RH engagement and strengthening IH communication during phonological processing may help rebalance hemispheric dominance and support stronger phonological and reading skills in children with and without reading difficulties. Our goal is to test the feasibility of this approach first in typically developing children, with future work extending the intervention to DD. We aim to design and implement a child-friendly EEG-neurofeedback (NF) intervention targeting IH processing during a phonological task.

The current pipeline is based on auditory N1/N100 responses elicited during passive dichotic listening (DL). Previous work has shown that more synchronized bilateral N1/N100 latencies during this task are associated with interhemispheric connectivity and corpus callosum properties, supporting their relevance to interhemispheric auditory–phonological processing. However, developing child-friendly EEG-neurofeedback systems requires neural features that can be extracted reliably from paediatric EEG data. Building on an initial proof-of-concept analysis in an existing paediatric dichotic-listening EEG dataset, the present study tested the pipeline in a newly collected neurofeedback-tailored DL dataset of 19 typically developing children aged 8–10 years. This allowed us to evaluate the N100 extraction approach in data collected with the task structure, electrode setup, and child-friendly design developed for the current project.

Specifically, we tested whether bilateral N100 responses could be robustly extracted using ROI averaging and canonical correlation analysis (CCA)-based spatial filtering, which estimates an optimized weighted combination of EEG channels, and whether CCA improved the reliability of the extracted ERP signal compared with conventional ROI averaging. The pipeline is also being extended with Residue Iteration Decomposition (RIDE), an ERP decomposition method designed to address latency variability in single trials, to further improve N100 estimation.

Methods

We analysed EEG data from 19 typically developing children aged 8–10 years. One additional participant was excluded because the experimental design was modified after the first recording. Children completed an active dichotic-listening task in which they reported syllables presented simultaneously to the two ears followed by a passive EEG dichotic-listening task consisting of four blocks of 168 linguistic trials. EEG was recorded during the passive task using a gel-based BrainVision actiCAP system with 46 electrodes, consisting of 32 standard 10–20 channels and 14 additional electrodes placed to increase coverage over central and temporal regions where auditory N100 responses are expected to be most prominent. Signals were sampled at 1000 Hz, with FPz used as ground and FCz as reference.

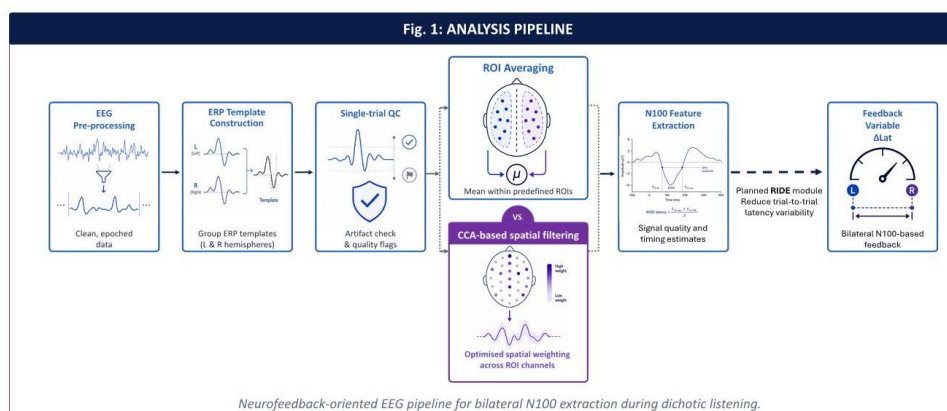
Continuous EEG was band-pass filtered and cleaned using Artifact Subspace Reconstruction and ICA-based artefact rejection^{^3}. Trial-level quality control was applied conservatively to preserve as many usable trials as possible, and only clearly contaminated trials were excluded based on ERP-correlation checks and robust amplitude/variance criteria. Trial-level quality control was applied conservatively to preserve as many usable trials as possible, and only clearly contaminated trials were excluded based on ERP-correlation checks and robust amplitude/variance criteria. Left- and right-hemisphere responses were estimated over fronto-central, central, centro-parietal and temporal regions^{^2}. We compared two spatial-filtering approaches: conventional ROI averaging and canonical correlation analysis (CCA)-based spatial filtering^{^4}. For each approach, we assessed group-level ERP morphology, single-trial correlation with the global ERP in the 0.1–0.4 s N100 window, and signal stability as a function of the number of trials included. The pipeline is further being extended with Residue Iteration Decomposition (RIDE)^{^5}, an ERP decomposition approach designed to separate latency-variable neural responses, to improve single-trial N100 estimation (Fig. 1).

Results

The conservative quality-control procedure retained most trials, with a median of 616 trials per child out of 672 recorded trials, ranging from 586 to 630 trials. Both ROI averaging and CCA recovered clear bilateral N100 responses at the group level. CCA improved the reliability of the extracted ERP signal compared with ROI averaging (Fig. 2a-d). At the subject level, median absolute ERP correlation was higher for CCA than ROI averaging in 18 of 19 children. Across subjects, the median of subject-level correlations was 0.463 for CCA and 0.362 for ROI averaging. A paired sign-rank test on subject-level medians confirmed this improvement, $p = 0.00025$. Stability analyses showed that CCA correlations increased with the number of trials included and reached high values within relatively small trial windows, supporting its suitability for reliable bilateral N100 extraction in paediatric EEG data.

Conclusions

These findings support the feasibility of extracting bilateral N100 responses from a neurofeedback-tailored dichotic-listening EEG protocol in children. CCA-based spatial filtering improved ERP signal reliability compared with conventional ROI averaging, providing a stronger basis for future online feature extraction. These results should be interpreted as technical validation of the signal-processing and calibration stage, not as evidence of neurofeedback efficacy. The next step is to integrate this RIDE module to further address single-trial latency variability before testing the closed-loop, game-based EEG-neurofeedback protocol.



References

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