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PALOMA VICTÓRIA DE SALES ALVES

NEURAL CORRELATES OF RETRIEVAL PRACTICE WITH FEEDBACK: AN EEG ANALYSIS AND METHODOLOGICAL PROPOSAL OF PYPELINE-EEG FOR SIGNAL PREPROCESSING AND ANALYSIS

João Pessoa
2025

Universidade Federal da Paraíba
Centro de Ciências Humanas, Letras e Artes
Programa de Pós-graduação em Neurociência Cognitiva e Comportamento

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Neural correlates of retrieval practice with feedback: an EEG analysis and methodological proposal of Pypeline-EEG for signal preprocessing and analysis

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ATA DE DEFESA (DISSERTAÇÃO)

Aos vinte e nove dias do mês de outubro de dois mil e vinte e cinco, às dez horas, em formato remoto (https://meet.google.com/hjg-pkto-rjk), reuniram-se em solenidade pública os membros da comissão designada pelo Colegiado do Programa de Pós-graduação em Neurociência Cognitiva e Comportamento para a defesa de dissertação de mestrado da discente **PALOMA VICTORIA DE SALES ALVES**, matrícula 20231024883. Foram componentes da banca examinadora os Professores Doutores: Carla Alexandra da Silva Moita Minervino (Presidente/coorientadora), Nelson Torro Alves (Membro Interno) e Diego Carvalho do Nascimento (Membro Externo à Instituição/NEOMA Business School). Dando início aos trabalhos, a presidente da banca, Profa. Carla Alexandra da Silva Moita Minervino, após declarar o objetivo da reunião, apresentou a examinanda PALOMA VICTORIA DE SALES SILVA e, em seguida, concedeu-lhe a palavra para que defendesse sua pesquisa, intitulada "Correlatos Neurais Associados a Prática de Recuperação com Feedback: uma Comparação Pré e Pós Sessão de Estudos". Passando então ao aludido tema, a examinanda foi a seguir arguida pelos examinadores na forma regimentar. Ato contínuo passou a comissão, em secreto, a proceder à avaliação e julgamento do trabalho, concluindo por atribuir-lhe o conceito "**APROVADO**", o qual foi proclamado pela presidência logo que esta foi franqueada ao recinto da solenidade pública. A versão final da dissertação deverá ser depositada em até 90 dias, contendo as modificações sugeridas pela banca examinadora. A discente não terá o título se não cumprir as exigências acima.

Nada mais havendo a tratar, eu, **Carla Alexandra da Silva Moita Minervino**, presidente da comissão examinadora, lavrei a presente ata, que depois de lida e aprovada por todos, assino juntamente aos demais membros da banca. João Pessoa, 29 de outubro de 2025.

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DEDICATION

À Mainha, por todo apoio;
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ideias em realidade sem impor limites.

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LIST OF ABBREVIATIONS AND ACRONYMS

ADHD	Attention-Deficit/Hyperactivity Disorder
BIDS	Brain Imaging Data Structure
CI	Confidence Interval
dB	Decibel
EC	Eyes Closed
EEG	Electroencephalography
EO	Eyes Open
FFT	Fast Fourier Transform
Hz	Hertz
ICA	Independent Component Analysis
ICLabel	Independent Component Labeling
kΩ	Kiloohms
M ± SD	Mean ± Standard Deviation
MNE	Magnetoencephalography and Electroencephalography Python Toolbox
POST	Post-intervention or post-session EEG recording
PRE	Pre-intervention or pre-session EEG recording
ROI	Region of Interest
SD	Standard Deviation

RESUMO

Do ponto de vista da neurociência cognitiva, a aprendizagem envolve a aquisição, o processamento e a retenção de informações. No contexto da educação formal, evidências indicam que a prática de recuperação acompanhada de feedback melhora a retenção de informações a longo prazo; contudo, ainda são escassas as demonstrações de seus substratos neurais. A banda Alpha tem sido associada a processos atencionais e, dado que a atenção prediz diversos desfechos cognitivos, este trabalho investigou se diferentes estratégias de estudo – pratica de recuperação com feedback e releitura – modulam a dinâmica espectro-temporal dessa banda. Participaram desta pesquisa 21 estudantes universitários, alocados aleatoriamente em três grupos: estudo ativo com prática de recuperação e feedback direcionado, estudo passivo com releitura e grupo controle. Antes do protocolo, todos responderam escalas de sonolência e motivação e a Bateria Psicológica de Avaliação da Atenção. Foram realizados dois registros de eletroencefalografia (EEG) – pré e pós intervenção – em condições de olhos abertos (EO) e olhos fechados (EC). Os sinais foram adquiridos com sistema BrainVision, pré-processados com filtragem, remoção de artefatos por ICA/ICLabel, referência média e segmentação das condições. A potência da banda Alpha foi analisada nos domínios espectral e temporal, comparando os momentos pré e pós-estudo entre grupos. Todo o processamento e análise foi realizado em Python, por meio do pipeline desenvolvido. O grupo ativo apresentou um aumento significativo nas regiões frontais, pré-frontais, centro-parietais e occipitais e uma tendência de diminuição na região temporo-parietal direita no pós protocolo de estudo. Não foi observado nenhuma diferença nos grupos passivo e controle. A prática ativa de recuperação com feedback demonstrou capacidade de modular a atividade alfa basal, sugerindo uma relação específica dessa estratégia de estudo sobre processos neurais ligados à atenção e aprendizagem. Além de contribuir empiricamente para a compreensão dos mecanismos neurais relacionados a prática de recuperação com feedback, este trabalho desenvolveu o Pypeline-EEG, um pipeline aberto e modular projetado para reduzir barreiras técnicas, padronizar etapas de análise e fortalecer a reprodutibilidade científica na neurociência, permitindo que outros pesquisadores realizem análises confiáveis sem depender de softwares proprietários ou de conhecimento avançado em programação.

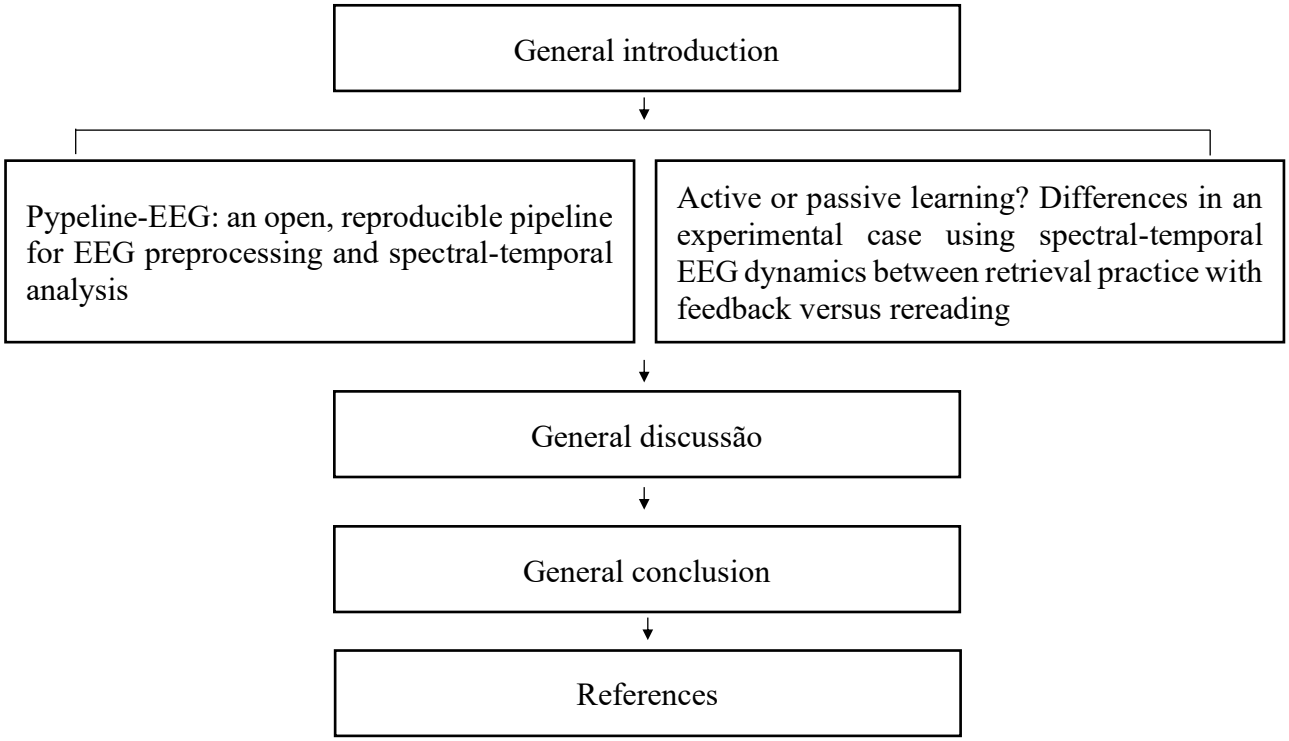
ABSTRACT

From the perspective of cognitive neuroscience, learning involves the acquisition, processing, and retention of information. In the context of formal education, evidence indicates that retrieval practice accompanied by feedback improves long-term information retention; however, demonstrations of its neural substrates remain scarce. The alpha band has been associated with attentional processes, and given that attention predicts several cognitive outcomes, this study investigated whether different review strategies – retrieval practice with feedback versus rereading – modulate the spectral-temporal dynamics of this band. A total of 21 undergraduate students participated in this study, randomly allocated into three groups: an active study group with retrieval practice and targeted feedback, a passive study group with rereading, and a control group. Before the protocol, all participants completed sleepiness and motivation scales as well as the Psychological Battery for Attention Assessment. Two electroencephalography (EEG) recordings – pre and post intervention – were performed under eyes-open (EO) and eyes-closed (EC) conditions. Signals were acquired using the BrainVision system, preprocessed with filtering, artifact removal via ICA/ICLabel, average referencing, and segmentation by condition. Alpha band power was analyzed in the spectral and temporal domains, comparing pre- and post-study measurements across groups. All data processing and analysis were performed in Python using the pipeline developed in this study. The active group showed a significant increase in alpha power in the frontal, prefrontal, centro-parietal, and occipital regions, along with a trend toward decreased power in the right temporo-parietal region after the study protocol. No meaningful differences were observed in the passive or control groups. These findings indicate that active retrieval practice with feedback can modulate baseline alpha activity, suggesting a specific effect of this study strategy on neural processes related to attention and learning. In addition to contributing empirically to the understanding of the neural mechanisms underlying retrieval practice with feedback, this work developed the Pypeline-EEG – an open, modular pipeline designed to reduce technical barriers, standardize analysis steps, and strengthen scientific reproducibility in neuroscience, enabling other researchers to perform reliable EEG analyses without relying on proprietary software or advanced programming expertise.

PRESENTATION

This dissertation is structured according to the ccandinavian model and consists of two articles. The first article proposes Pypeline-EEG, an open and modular workflow developed to ensure reproducibility and transparency in the preprocessing and analysis of EEG data. The second article investigated whether different study strategies modulate Alpha band activity, exploring the neural correlates associated with attentional regulation during the learning process.

The following sections comprise the general discussion and the general conclusion, which integrate the theoretical and methodological findings, highlighting their contributions to the fields of neuroscience, education, and open Science. Finally, the dissertation concludes with the references and supporting materials.



GENERAL INTRODUCTION

Interest in factors related to the academic performance of university students has been steadily increasing. Between 2013 and 2018, 18,875 articles addressing this topic were published, whereas between 2019 and 2024 this number rose to 26,794. These data were obtained from a search on the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior ({CAPES}) journal platform (2024) using the term "academic performance university." Particularly during and after the pandemic, significant gaps in the educational system became evident, gaps that had already been discussed previously but gained new prominence as teaching practices and students daily routines had to adapt to a changing social and technological context.

Academic performance is commonly measured through short, medium, and long term activities proposed by educational institutions, which are then converted into cumulative averages that determine students approval or failure in a given course (Hellas et al., 2018). Scores below the institutional cutoff averages are interpreted as indicators of low performance. It is understood that numerous factors contribute to this metric, making it a central focus of research for many scholars. A recent review (Al-Tameemi et al. 2023) sought to compile these studies to identify which factors are most strongly associated with low academic performance among university students.

The factors were divided into four main categories: (1) personal factors, generally related to health and emotional regulation; (2) social factors, including cultural identity, language barriers, and interpersonal relationships; (3) demographic factors, associated with race, gender, and ethnicity; and (4) academic factors, encompassing disengagement, lack of motivation, and the use of ineffective study methods and techniques. These categories converge on a common element: they negatively impact the learning process.

From the perspective of cognitive science, learning is defined as the acquisition, processing, and retention of new information through interactions with the environment (Dehaene, 2021). This process requires essential cognitive abilities, including (1) attention (Buhler, 2024), a system composed of multiple networks responsible for maintaining alertness, orientation, and executive control (Petersen & Posner, 2012; Posner & Petersen, 1990); (2) memory (Salame et al., 2024), the ability to encode, store, and retrieve semantic and episodic information (Squire, 1992; Tulving, 1972); and (3)

executive functions (Pascual et al., 2019), a set of higher-order cognitive processes that enable goal-directed behavior (Miyake & Friedman, 2000).

Learning, therefore, is a biological product, made possible by the phenomenon of neuroplasticity. Neuroplasticity allows the brain to reorganize itself by forming or strengthening neural networks in response to environmental experiences (Sagi et al., 2012). As the brain adapts and these networks are reinforced, not only is access to information facilitated, but a deeper integration of knowledge also occurs (Carpenter, 2009).

For this process to occur efficiently, cognitive effort is required through strategies such as retrieval practice (Rea et al., 2022) and corrective mechanisms like feedback and feedforward, which help individuals adjust their learning approaches to achieve specific goals (Wisniewski et al., 2020). In academic settings, learning is typically measured through behavioral responses, often in the form of tests designed to assess performance in a particular domain of knowledge.

A large meta-analysis conducted by Hattie (2023) sought to broadly examine the factors influencing the learning process. In the context of university students, the analysis revealed that the factors most strongly associated with performance variation are those related to self-regulation and learning strategies. Previous research has shown that students are often highly engaged in learning methods considered ineffective (Dunlosky et al., 2013; Karpicke & Blunt, 2012; Morehead et al., 2016), and recent studies suggest that this preference remains prevalent due to the low effort these methods require (Donoghue & Hattie, 2021), even when students are aware of which strategies are more or less effective (Rea et al., 2022).

The results of another meta-analysis, this time evaluating the effectiveness of study methods (Donoghue & Hattie, 2021), indicate that distributed practice ($d = 0.85$) and retrieval practice ($d = 0.74$) are the most effective techniques for improving long-term information retention and performance on knowledge-based assessments. In contrast, rereading ($d = 0.47$), highlighting ($d = 0.44$), and summarizing ($d = 0.44$) were found to be less effective for the same purpose. These indices demonstrate that the most beneficial practices are those involving active engagement from the learner.

Retrieval practice can be defined as the mental effort to recall information (Roediger & Karpicke, 2006a) without consulting supplementary materials. The benefits of retrieval practice for memory were already hypothesized even before empirical research was conducted (James, 1890) argued that exerting an internal effort to recall information would be more valuable for learning than simply reviewing it.

Subsequent empirical work by Abbott (1909) was structured to test this premise by comparing whether reading alone or alternating between reading and retrieval yielded better outcomes. The results suggested that retrieval practice led to greater retention of the studied content. Later studies (Roediger & Karpicke, 2006a, 2006b) revisited this hypothesis and reached similar conclusions, demonstrating that retrieval practice plays a fundamental role in long-term memory retention. From these pioneering studies, interest in this topic grew exponentially, leading to a substantial body of research and the development of theoretical models to explain it.

Table 1. *Summary of the main theories that aim to explain the retrieval-based learning process. Table created by the author based on information provided by Karpicke, 2017.*

Theory	Proponents	Brief description	Core idea
Transfer-Appropriate Processing	Kolers e Roediger (1984); Morris et al. (1977)	Suggests that performance is improved when the type of processing during retrieval practice matches the processing required in the final assessment.	Alignment between the cognitive processes involved in retrieval practice and those required in the final evaluation.
Strength and Retrieval Effort	Bjork e Bjork (2011)	States that the effort involved in retrieval strengthens memory, and that desirable difficulty enhances retention.	Retrieval is more effective when it requires cognitive effort, thereby promoting long-term retention.
Elaborative Retrieval Account	Carpenter (2009)	Proposes that retrieval activates semantic networks, leading to the formation of more elaborate and interconnected memory traces.	Retrieval activates related information, strengthening memory through elaboration.
Episodic Context Account	Karpicke et al. (2014)	Suggests that during retrieval, the temporal and episodic context associated with an item is updated, facilitating subsequent retrievals.	Retrieval updates contextual cues, improving the future accessibility of memory.

The main theories presented guide the understanding of how retrieval practice influences learning. However, a significant current debate concerns the fact that these

theoretical models generally do not account for individual differences in their propositions (Karpicke, 2017). Recent studies have highlighted, for instance, that retrieval practice may be beneficial only for individuals with high working memory capacity (Zheng et al., 2023). According to this framework, the premise is that individual resources governing the interaction between long-term memory and working memory mediate greater or lesser retention of information (Zheng et al., 2024).

Nonetheless, another study with a larger and more robust sample (Jonsson et al., 2021) reported findings that emphasize the validity of retrieval practice for information retention regardless of cognitive ability level. This effect also appears to hold independently of motivational and emotional factors (Glaser & Richter, 2023). Even when initial test performance is not particularly strong (Chan et al., 2024), distributed practice combined with appropriate feedback leads to improved long-term retention.

It is important to note that most research on retrieval practice has been predominantly behavioral. Another recurring gap identified in several review studies (McDermott, 2021; Pan et al., 2024) is the lack of investigations focusing on neural substrates and the cognitive mechanisms underlying the testing effect. Research in this direction was initiated previously (Van den Broek et al., 2016) through neuroimaging data, which generally suggest that retrieval leads to greater neural engagement and improved retention, particularly when compared to low-engagement learning methods (Stillesjö et al., 2021). Such effects appear to extend even beyond individual differences (Wiklund-Hörnqvist et al., 2022) and neurodiversity (Knouse et al., 2020). However, these studies remain scarce and do not yet represent a consensus regarding the specific neural substrates or mechanisms involved.

What seems well established is that retrieval practice, when applied in a distributed manner and accompanied by feedback, promotes greater information retention (Agarwal et al., 2021; Pan & Rickard, 2018). Distributed practice, which consists of revisiting content actively and periodically over time (Cepeda et al., 2006), is commonly associated with retrieval practice (Karpicke & Bauernschmidt, 2011; Karpicke & Roediger, 2007; Latimier et al., 2021; Trumble et al., 2024) because it helps counteract the natural forgetting curve (Murre & Dros, 2015). In this sense, another key element that enhances retrieval practice in improving retention is feedback (Wisniewski et al., 2020). Feedback refers to information provided in response to an individual's performance or

action (Hattie & Timperley, 2007) and plays a central role in the learning process by both reinforcing correct responses and correcting errors (Li et al., 2024).

Although these strategies are well-aligned and widely recognized in the literature as favorable to learning, retrieval practice is still used almost exclusively as an assessment tool, typically through exams (Pan et al., 2024), within educational institutions. A review (Carpenter, 2023) identified this barrier and proposed several approaches to overcome it: (1) education and dissemination, to raise awareness of the benefits of retrieval practice beyond academic literature; (2) direct experience, providing students with opportunities to experience its benefits firsthand; (3) feedback provision, offering detailed feedback based on these experiences; and (4) curricular integration, embedding retrieval practice as a core element of classroom learning strategies.

From the students perspective, the perceived barriers to adopting retrieval practice include: (1) the perceived cost-benefit imbalance, as students often fail to recognize its advantages and thus find it unappealing due to the effort required; (2) self-efficacy, since many do not know how to implement the practice effectively in their study routines; and (3) high levels of anxiety and stress, as students tend to associate retrieval practice with evaluative or testing situations (Rea et al., 2022).

In this context, aiming to overcome these barriers and to support the learning process of students in fields related to neuroscience, NeuroShow was developed (Alves et al., 2023). This platform was designed to provide free and accessible multiplatform learning tools (web, Android, and iOS) that allow students to study through methods empirically proven to enhance learning outcomes (Alves et al., 2024). It is composed of four main sections:

1. Predefined quizzes, organized by neuroscience-related themes, in which questions are presented one at a time to minimize distractors. The quizzes are formatted as multiple-choice questions with immediate and personalized feedback for each alternative.
2. A space for creating themes and spaced-repetition cards, where students can generate an unlimited number of study topics and add flashcards containing questions (front) and answers (back) associated with each topic. Based on this

input, the algorithm developed by the research team processes the student's self-rated difficulty for each card and notifies the optimal time for review.

3. A profile section, enabling users to access metrics about their progress, such as accuracy rates, error frequency, study frequency, and average difficulty levels.

4. A scientific dissemination hub, functioning as the platform's homepage, dedicated to sharing, discussing, and promoting events and projects related to evidence-based educational practices. This space features projects, publications, videos, and events with direct links for registration or access to their respective platforms, aiming to foster scientific outreach beyond institutional boundaries in an accessible and democratic way – encouraging students to integrate such practices into their study routines.

This type of pedagogical, technological, and multiplatform tool enables students to engage more effectively with evidence-based study habits and best practices (Naveed et al., 2023; Yeap et al., 2016), which in turn can potentially enhance their academic performance metrics (Chugh et al., 2023; Valverde-Berrocoso et al., 2022). However, the adoption of such tools in students' study routines depends on three main factors: (1) the extent to which students perceive the platform as suitable for their individual needs, (2) whether the platform is enjoyable and user-friendly, and (3) whether students are able to perceive its effectiveness in their own routines (Qashou, 2021).

Through this instrument, previously mentioned challenges, such as accessibility, education, and awareness of retrieval practice, can be mitigated (Alves et al., 2024). In this sense, the overarching goal becomes to overcome the remaining barriers by fostering and conducting research that addresses gaps related to the neural substrates and mechanisms underlying the practice.

Attentional capacity is a crucial factor for retrieving correct semantic information efficiently (Vijayarajah & Schlichting, 2024) and is a strong predictor of other cognitive abilities, being essential for their effective development and functioning (Posner & Rothbart, 2007). Therefore, when initiating a discussion about the cognitive skills that precede enhanced information retention through retrieval practice, attentional capacity cannot be overlooked. Accordingly, the primary objective of this research project is to investigate whether differences exist in attentional responses and attentional capacity

depending on the study method used, comparing active learning strategies implemented via the NeuroShow digital platform (which incorporates evidence-based retrieval and feedback techniques) with less effective strategies such as rereading summaries.

Electroencephalography (EEG) is one of several techniques used to monitor neural activity. Through EEG devices, it is possible to record the postsynaptic electrical activity of large neuronal networks and subsequently analyze and interpret these signals (Niso et al., 2023). This method is widely used due to its noninvasive nature and high temporal resolution (Cohen, 2014). However, these advantages come with technical challenges, particularly regarding equipment setup, data acquisition, preprocessing, and analysis. To address these challenges, a custom EEG analysis pipeline was developed, based on best-practice principles, to assist in the preprocessing, spectral, and temporal analysis of EEG data.

Finally, variables related to attention, sleep, and motivation were controlled, as all of them exert significant influence on attentional processes. Sleep deprivation negatively impacts both sustained attention (Lim & Dinges, 2010) and attentional efficiency (Durmer & Dinges, 2005). Moreover, motivation has been shown to increase focus and engagement in cognitive tasks, leading to better performance outcomes (Ryan & Deci, 2000). The integration of these instruments and levels of analysis enables a comprehensive and detailed interpretation of the cognitive and neural resources involved in retrieval practice.

RESEARCH QUESTION AND HYPOTHESES

(Q1) Are retrieval practice with feedback and rereading, as different study strategies, capable of modulating the spectral–temporal dynamics of Alpha band activity?

(H0) None of the study strategies significantly modulate Alpha band activity between the pre and post study moments within each group.

(H1) Retrieval practice with feedback significantly modulates Alpha band activity between the pre and post study moments.

(H2) The rereading strategy does not produce a significant modulation of Alpha band activity between the pre- and post-study moments.

These hypotheses assume that retrieval practice with feedback, by involving greater cognitive effort (Bjork & Bjork, 2011) and activating semantic networks associated with the studied content (Carpenter, 2009), combined with immediate feedback that guides the learner (Hattie & Timperley, 2007) through the correction of errors or reinforcement of correct responses (Li et al., 2024), promotes adjustments in the dynamics of the Alpha band, a well-established marker of attentional regulation (Jensen & Mazaheri, 2010). In contrast, rereading would tend to maintain the baseline pattern of Alpha band activity, as it requires lower levels of cognitive engagement compared to retrieval practice with feedback (Donoghue & Hattie, 2021).

Paper 1.

The article entitled “Pypeline-EEG, an open and modular workflow developed to ensure reproducibility and transparency in the preprocessing and analysis of EEG data” was removed from the final version of this dissertation due to copyright issues, as it was submitted to the journal *Scientific Data*.

Paper 2.

The article entitled “Active or passive learning? Differences in an experimental case using spectral-temporal EEG dynamics between retrieval practice with feedback versus rereading” was removed from the final version of this dissertation due to copyright issues, as it was submitted to a *Learning and Motivation*.

GENERAL DISCUSSION

The main objective of this dissertation was to examine whether different study strategies, specifically retrieval practice with feedback versus rereading, modulate the spectro-temporal dynamics of the Alpha band. To this end, 21 neurotypical university students were randomly assigned to two experimental groups, active study (retrieval practice with directed feedback) and passive study (rereading), and one control group, in order to identify whether spectro-temporal differences would emerge between groups.

The results showed that only the group that underwent the active study protocol exhibited significant and sustained changes in Alpha band power after the study session, specifically during the eyes-open condition. These findings suggest that retrieval practice with feedback can modulate Alpha activity in key regions involved in attentional regulation (Corbetta & Shulman, 2002; Buschman & Kastner, 2015). This modulation was characterized by increased Alpha activity across prefrontal, frontal, frontocentral, central, centro-parietal, temporo-parietal, and occipital regions, along with a slight trend toward reduced Alpha power in the right temporo-parietal area. From a neurofunctional perspective, these findings support the hypothesis that retrieval practice with feedback induces functional reorganizations in Alpha activity associated with greater attentional readiness and cortical efficiency (Henz et al., 2018; Klug et al., 2022), which can still be observed even during rest.

It is noteworthy that this difference between sessions was found only in Group A, despite all groups exhibiting equivalent control variable indices, as confirmed by the Brown–Forsythe test for homogeneity of variances. This reinforces the interpretation that the observed modulation resulted directly from the study protocol. Another factor supporting this conclusion was the methodological rigor applied throughout the EEG data handling process, from participant recruitment and data acquisition standardization to data organization and analysis, all following the current best-practice recommendations for EEG studies (Keil et al., 2013; Pernet et al., 2020). After organizing the data according to the BIDS standard, a complete preprocessing pipeline was applied, including automatic artifact removal via ICA and source classification through the ICLabel algorithm, using open-source Python tools.

This methodological framework gave rise to the second article of this dissertation, which systematically documents and openly provides the developed workflow,

establishing it as a reproducible, freely accessible tool for EEG preprocessing and spectral-temporal analysis, adaptable to other datasets and experimental contexts.

In summary, the findings suggest that study protocols combining retrieval practice with immediate feedback may enhance not only academic performance but also the neural efficiency underlying attention and cognitive self-regulation. Within educational settings, structuring learning experiences that stimulate active information retrieval, either before or after content exposure, may facilitate the reorganization of attentional networks, thereby preparing students to process and integrate new knowledge more effectively (Pan & Sana, 2021).

GENERAL CONCLUSION

The outcome of this work represents a significant advancement in the state of the art concerning the neural mechanisms associated with retrieval practice with feedback, as well as in the field of open and reproducible science for handling EEG data. From a theoretical perspective, the results expand our understanding of the neural mechanisms that may underlie retrieval practice with feedback, indicating that the Alpha band can be modulated by such practices in ways that optimize the reorganization and efficiency of attentional networks. From a methodological perspective, the release of Pypeline-EEG contributes to the transparency, reproducibility, and replicability of EEG-based research across different contexts.

For future studies, increasing the sample size and integrating behavioral measures, such as participants' subsequent performance, as well as recording EEG during the retrieval practice itself, would help deepen our understanding of the underlying mechanisms and their practical implications. Examining the Alpha band dynamics in interaction with other frequency bands could also provide further insights. It is also worth emphasizing that, regardless of the application scenario, Pypeline-EEG can be easily employed due to its highly modular and adaptable architecture.

By integrating experimental evidence on retrieval practice with feedback with technical innovation through the development of a highly reusable analysis pipeline, this work establishes a research model that bridges open science, evidence-based education, and applied neuroscience. This integration advances our understanding of learning processes and, in practical terms, demonstrates how they can be optimized through active and feedback-driven study strategies.

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APÊNDECES

APÊNDECE I

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Prezado(a): _____

As pesquisadoras Paloma Victória de Sales Alves, Profa. Dra. Carla Alexandra da Silva Moita Minervino e Melyssa Kellyane Cavalcanti Galdino convidam você a participar da pesquisa intitulada "***Correlatos neurais e comportamentais associados ao uso do neuroshow versus métodos de estudos tradicionais: uma comparação pré e pós sessão de estudos***". Para tanto, você precisará aceitar o Termo de Consentimento Livre e Esclarecido presente na tela inicial do cadastro no site https://neuroshow.com.br/, que visa assegurar a proteção, a autonomia e o respeito aos participantes de pesquisa em todas as suas dimensões: física, psíquica, moral, intelectual, social, cultural e/ou espiritual – e que a estruturação, o conteúdo e forma de obtenção dele observam as diretrizes e normas regulamentadoras de pesquisas envolvendo seres humanos preconizadas pela Resolução 466/2012; Resolução 510/2016 e Carta Circular nº 1/2021 do Conselho Nacional de Saúde e Ministério da Saúde.

Sua decisão de participar neste estudo deve ser voluntária e que ela não resultará em nenhum custo ou ônus financeiro para você (ou para o seu empregador, quando for este o caso) e que você não sofrerá nenhum tipo de prejuízo ou punição caso decida não participar desta pesquisa. Todos os dados e informações fornecidos por você serão tratados de forma anônima/sigilosa, não permitindo a sua identificação.

Esta pesquisa tem como objetivo geral verificar se há diferença na resposta atencional de estudantes a depender do método de revisão utilizado durante as sessões de estudos. Para isso, utilizaremos um questionário de caracterização dos estudantes, o *NeuroShow*, escala *Karolinska* de sonolência, escala de motivação, aparelho de eletroencefalografia e a Bateria Psicológica para Avaliação da Atenção II (BPA II).

Riscos e benefícios ao participante da pesquisa

O projeto de pesquisa seguirá as normas vigentes na Resolução Nº 510, de 07 de abril de 2010, que se refere aos processos éticos de coleta de dados em pesquisas das Ciências Humanas e Sociais. Ao envolver-se com a pesquisa, o participante receberá uma devolutiva acerca dos dados coletados. Os possíveis riscos durante a participação do

indivíduo são mínimos, poderão relacionar-se ao cansaço ou aborrecimento, sem riscos de origem física.

Informações de contato da responsável principal

Paloma Victória de Sales Alves

Mestranda no Programa de Pós Graduação em Neurociência Cognitiva e Comportamento, Universidade Federal da Paraíba (UFPB)

palomavictoria14@gmail.com (83) 987902621

Endereço e informações de contato da Universidade Federal da Paraíba

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Telefone: +55 (83) 3216-7200

E-mail: nesmep.ufpb@gmai.com Homepage: https://ufpb.br

Horário de funcionamento: 07h às 12h e das 13h às 17h

Endereço e informações de contato do Comitê de Ética em Pesquisa (CEP) CCS – UFPB

Comitê de Ética em Pesquisa (CEP)

Centro de Ciências da Saúde (1º andar) da Universidade Federal da Paraíba

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http://www.ccs.ufpb.br/eticaccsufpb

Horário de Funcionamento: de 07h às 12h e de 13h às 16h.

CONSENTIMENTO LIVRE E ESCLARECIDO

Ao colocar sua assinatura ao final deste documento, **VOCÊ**, de forma voluntária, na qualidade de **PARTICIPANTE** da pesquisa, expressa o seu **consentimento livre e esclarecido** para participar deste estudo e declara que está suficientemente informado(a), de maneira clara e objetiva, acerca da presente investigação. E receberá uma cópia deste **Termo de Consentimento Livre e Esclarecido (TCLE)**, assinada pelo(a) Pesquisador(a) Responsável.

João Pessoa, PB. _____/_____/_____

Assinatura, por extenso, do(a) participante da pesquisa

Assinatura, por extenso, da pesquisadora responsável

APÊNDECE II

QUESTIONÁRIO DE CARACTERIZAÇÃO DO ESTUDANTE

1. Dados Demográficos

- **Idade:** _____ anos
- **Sexo:**
  - ( ) Masculino
  - ( ) Feminino
  - ( ) Outro
- **Você é destro?**
  - ( ) Sim
  - ( ) Não
- **Está atualmente matriculado no ensino superior?**
  - ( ) Sim
  - ( ) Não

2. Histórico Acadêmico

- **Curso que está cursando:**
- **Ano/Semestre em que está matriculado, e qual o período equivalente?**
- **Quais disciplinas de áreas afins das neurociências você já cursou?**
- **Quais estratégias de estudo você utilizada regularmente para estudar para uma prova?**
- **Você já enfrentou dificuldades acadêmicas significativas (como reprovações, baixo desempenho representado pelas notas, etc.)?**
  - ( ) Sim
  - ( ) Não

3. Saúde e Condições Cognitivas

- **Você já recebeu diagnóstico de algum dos seguintes transtornos?**
  - ( ) Transtorno do Déficit de Atenção e Hiperatividade (TDAH)
  - ( ) Dislexia

- ( ) Outro transtorno neurológico: _____
- ( ) Outro transtorno psiquiátrico: _____
- ( ) Nenhum desses

- **Você faz uso contínuo de medicamentos psicotrópicos (como antidepressivos, ansiolíticos, antipsicóticos ou psicoestimulantes)?**
  - ( ) Sim
  - ( ) Não

4. Padrão de Sono

- **Quantas horas você costuma dormir por noite?**
  - ( ) Menos de 5 horas
  - ( ) Entre 5 e 6 horas
  - ( ) Entre 6 e 7 horas
  - ( ) Entre 7 e 8 horas
  - ( ) Mais de 8 horas
- **Você costuma ter dificuldades para dormir ou problemas relacionados ao sono?**
  - ( ) Sim
  - ( ) Não
  - Se sim, descreva brevemente: _____

5. Dados Socioeconômicos

- **Renda familiar mensal:**
  - ( ) Até 2 salários mínimos
  - ( ) Entre 2 e 5 salários mínimos
  - ( ) Entre 5 e 10 salários mínimos
  - ( ) Acima de 10 salários mínimos
- **Você possui bolsa de estudos ou algum tipo de financiamento para sua educação?**
  - ( ) Sim
  - ( ) Não
- **Você trabalha enquanto estuda?**
  - ( ) Sim, em tempo parcial

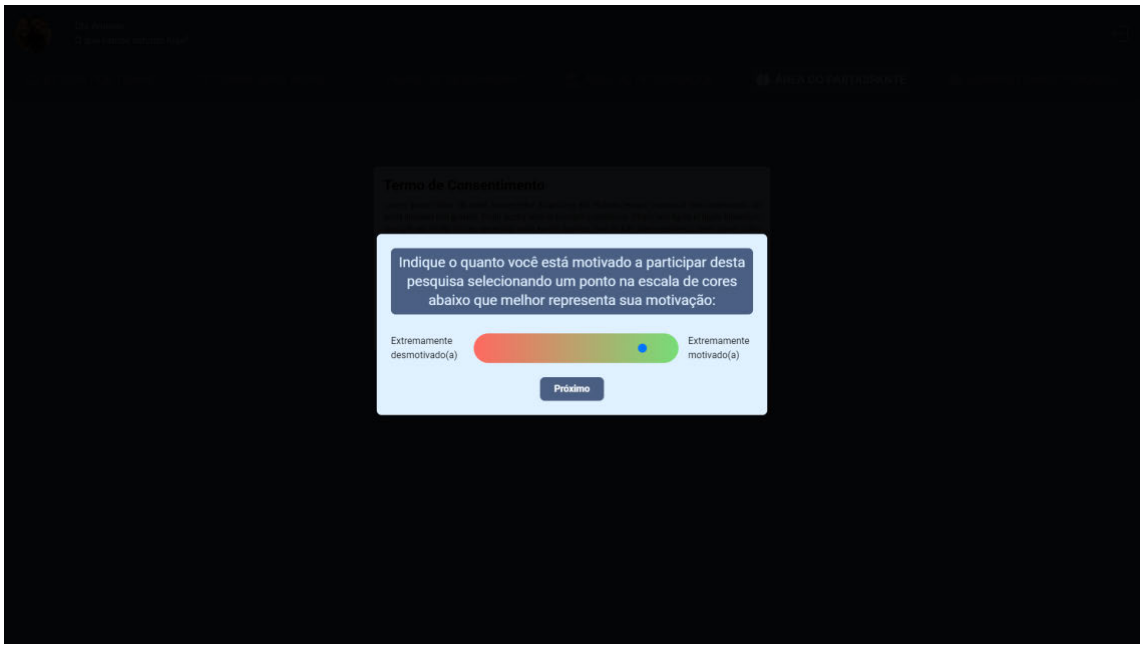
- ( ) Sim, em tempo integral
- ( ) Não

- **Com quem você reside atualmente?**
  - ( ) Sozinho(a)
  - ( ) Com familiares
  - ( ) Com amigos
  - ( ) Outro: _____

APÊNDECE III

ESCALA DE MOTIVAÇÃO BASEADA EM GRADIENTE DE CORES

Durante a coleta, a escala foi disponibilizada aos participantes através do site neuroshow.com.br, em sua respectiva aba de participantes da pesquisa.

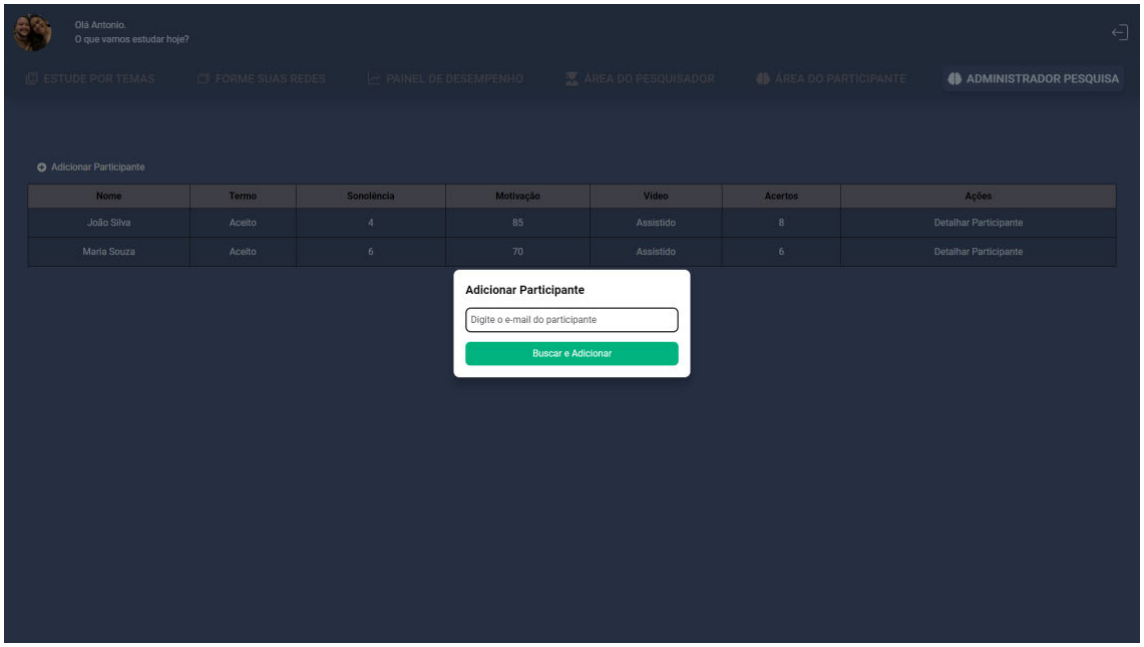


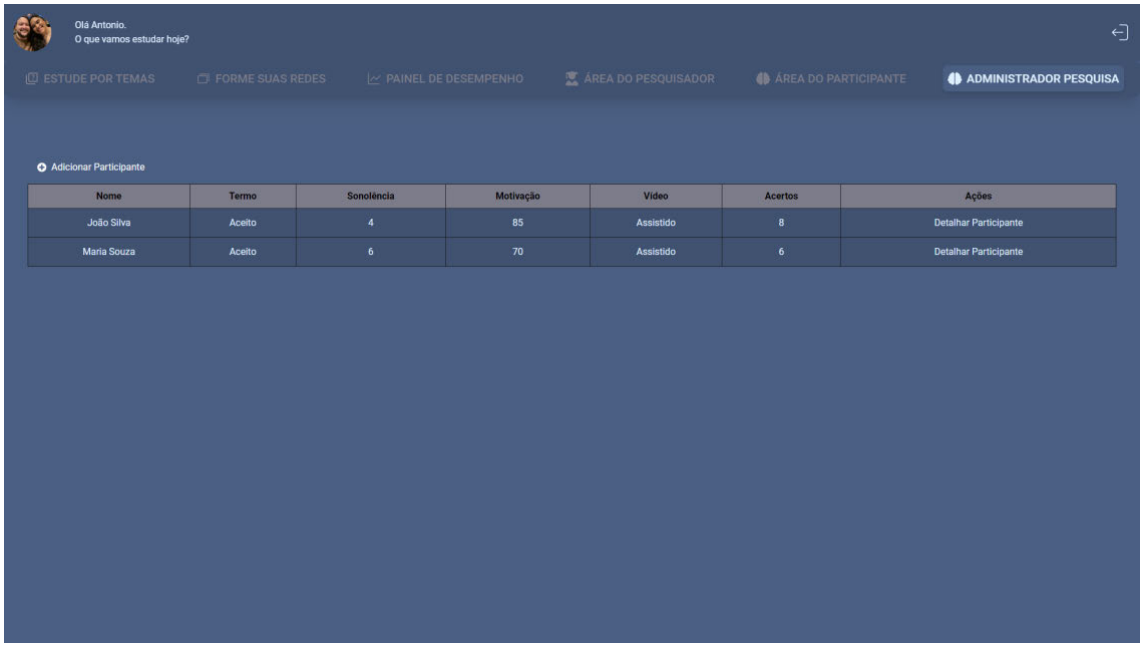
APÊNDECE IV

ÁREA DO PESQUISADOR

As informações coletadas através dos instrumentos foram registradas e armazenadas nesta aba, a fim de tornar o acompanhamento e a análise de dados simples, estruturada e segura.

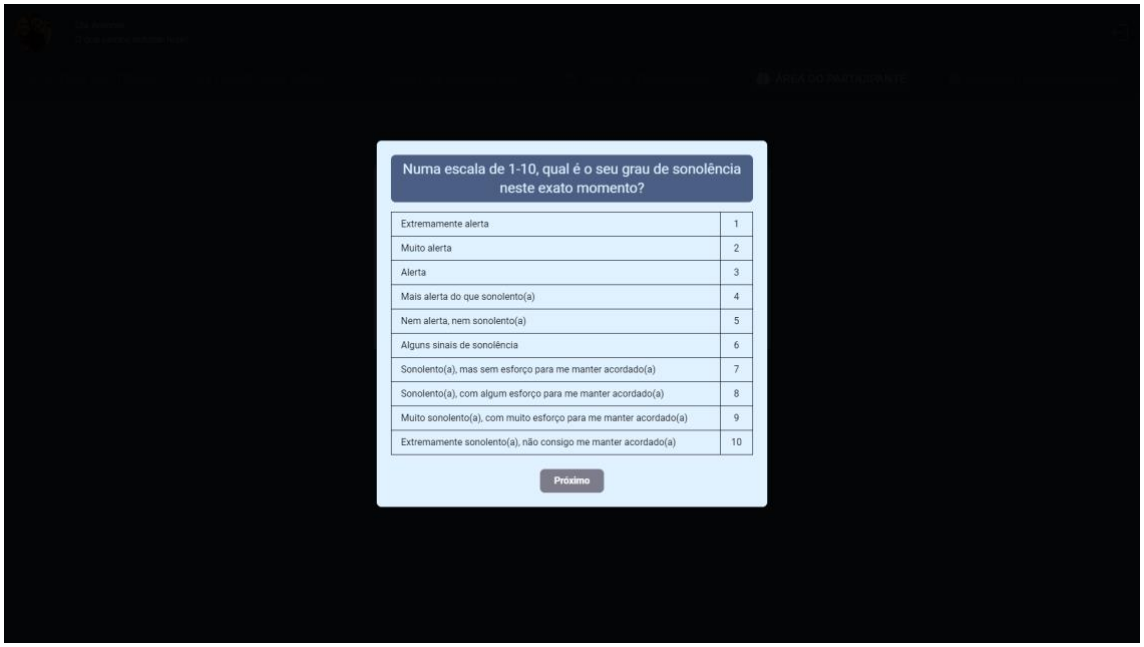
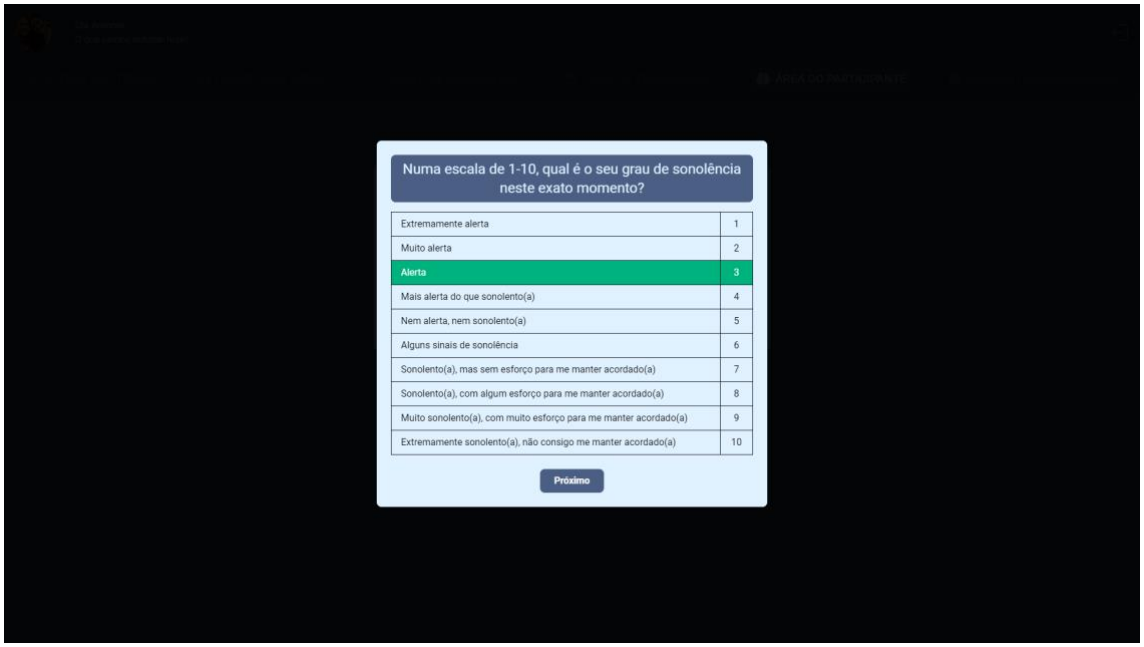
Telas de registro e acompanhamento das métricas dos participantes





ANEXOS

ANEXO I

ESCALA KAROLINSKA DE SONOLÊNCIA (ADAPTADA)

Esta é uma representação da escala karolinska de sonolência, adaptada. Durante a coleta, a escala foi disponibilizada aos participantes através do site neuroshow.com.br, em sua respectiva aba de participantes da pesquisa.