Open Peer Review on Qeios

Auto Train Brain increases the gamma band entropy variance more in the left temporal region than that in the right temporal region with 14 channel headset in Dyslexia: Pilot study

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Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.

Abstract

Auto Train Brain is a mobile app that aims to improve reading comprehension and speed for people with dyslexia through neurofeedback. Clinical trials have been conducted to examine the efficacy of neurofeedback on dyslexia. However, accurately measuring long-term outcomes with rapidly changing EEG data can be challenging without the use of psychometric tests. To overcome this issue, a novel measurement method was developed using the variance of sample entropy calculated in the gamma band to compare different sessions. Results of the study showed that after 100 sessions, the 14-channel neurofeedback with Auto Train Brain was more effective in increasing the variance of gamma band entropy in the left temporal lobe (T7) compared to the right temporal lobe (T8). Using the measurement of gamma band entropy variance was identified as a suitable approach to assess the success of neurofeedback.

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Keywords: Neurofeedback, sample entropy, Auto Train Brain, learning disorders, dyslexia, EEG.

I. Introduction

Dyslexia is a subcategory of Specific learning disorders according to DSM V criteria[1]. Some people struggle with reading, despite having IQs that are normal or above average [2]. Regarding the underlying cause of dyslexia, numerous theories have been proposed. The genetic origin of dyslexia is the most well-known of these explanations [3]. Children

who have dyslexia are more likely to have dyslexic parents [4]. According to [5], dyslexia is distinguished by significant underactivity in the reading network, disturbed functional connections, and variations in structural connections in specific fiber tracts.

Even if children with dyslexia receive the necessary supportive education and adequate nutrition, it takes a very long time to close the gap between their peers [6]. Sometimes this difference cannot be closed during their lifetime. One or more parts of phonological processing are missing, such as the ability to consciously manipulate speech sounds (phonological awareness), to temporarily store phonological information in the verbal short-term memory, and to quickly retrieve long-term phonological representations [6].

It is hypothesized that there is a disconnection syndrome in the left temporal lobe of dyslexia[7]. QEEG measurements display the increased slow brain waves in the left temporal region of the dyslexic brain [8] and/or there may be general EEG slowing. Temporal lobes are important for brain maturation and functional connectivity, and this connectivity seems missing in dyslexia [9].

There are various subtypes of dyslexia. A number of recent studies have also discovered that dyslexia has been strongly linked to various characteristics, including underlying basic auditory processing deficiency [10], impaired visual processing [11], attentional deficits [12], defective eye movements [13], and irregularities of processing [14][15] and some have defects in combining the visual and auditory input in the left angular gyrus [16]. As per [17], individuals with dyslexia struggle to decode written graphemes into their corresponding phonemes efficiently.

Dyslexia causes problems in understanding words, pronunciation, and syllables. Because of this, a child with dyslexia frequently struggles with language and verbal expression and is unable to distinguish between words based on their phonemes due to poor hearing and comprehension skills. These children are normal in other aspects or just a little smarter than average. They might be daydreamers dealing with low self-esteem, anxiety, and despair as a result of their academic struggles [18].

Studies have indicated that children with dyslexia display slow waves at FC5 and F7, and do not exhibit beta-1 activity desynchronization while performing reading tasks in regions associated with Broca's area (FC5), the Angular gyrus (CP5, P3), and the left parieto-occipital area (P7, O1) involved in semantics and mathematics comprehension [19], while the right temporal and parietal areas (P8 and T8) exhibit elevated sluggish activity [20]. According to researchers, there is a disruption in the left temporal region [21]. Furthermore, individuals with dyslexia and ADHD may experience high levels of frontal sluggish activity and increased coherence in the delta and theta bands symmetrically at T3 and T4, while the alpha and beta bands show a distinct right-temporal central increase in coherence [20]. Bi-hemispheric hyper-coherence (between T3 and T4) is observed in the delta and theta bands, whereas hypo-coherence in the delta, theta, and alpha bands is present between P7 and O1. Dyslexia is also associated with gamma band issues and less functional connections, with the left and right temporal lobes being the sources of healthy functional connections. [22][23].

Neurofeedback has been established as a technique that can improve the consequences of dyslexia by allowing the subject to gain more control over their brain through operant conditioning [24]. This phenomenon has been shown to add

weak connections that can help the subject pay attention and learn better when they learn to manage a specific brain area [25]. The American Psychological Association (APA) recognizes neurofeedback as a "possibly efficacious" technique [26]. While demonstrating the effectiveness of neurofeedback can be challenging, clinical studies have shown advancements in psychometric tests used before and after the investigation [27]. Furthermore, several studies have shown that neurofeedback leads to improvements in brain structure, including improved functional connectivity of the sensorimotor resting state network and increased fractional anisotropy (FA) in the corpus callosum after one hour of NFB training. The default mode network also showed increased functional connectivity [28]. While fMRI is typically used in these studies to display strongly linked brain regions following neurofeedback, it is challenging to demonstrate changes in the brain using QEEG. However, research has shown a causal relationship between neurofeedback and cognitive improvement [29][30][31][32].

Auto Train Brain is an advanced solution that includes neurofeedback from 14 channels, multimodal learning, and special education principles [33][34]. Machine learning algorithms are built-in features of Auto Train Brain.

In this research, we have compared the variance of gamma band entropy in the temporal lobes during 14-channel neurofeedback for dyslexia with Auto Train. Due to the challenges of measuring long-term results with rapidly changing EEG data, a new measurement method was developed using the variance of sample entropy calculated in the gamma band.

II. Materials & Methods

A. Subjects & Experimental Data

In this experiment, 40 dyslexic children participated providing their written consent both from themselves and from families according to the rules set by the research ethics committee. Their ages differ from 7 to 10 (34 males, 6 females). They have used Auto Train Brain (a clinically-tested mobile app for applying neurofeedback from 14 channels or 5 channels) more than 100 times to improve their reading speed and reading comprehension. The recruitment period was 6 months.

The children in the experimental group were diagnosed with dyslexia by psychiatric professionals, who then recommended that their families use Auto Train Brain at home. The TILLS tests were used by psychologists and psychiatrists to examine whether the individuals met the DSM-V dyslexia criteria. The children chosen to participate in the experiment were chosen at random. The participant's primary goal in the retrospective study is to use Auto Train Brain software as a neurofeedback device at home.

The participants utilized Auto Train Brain before leaving for school in the morning. The study's inclusion requirements stipulated that participants must be of middle socioeconomic status, be drug-free, and have dyslexia as their only comorbid condition, and be aged between 7-10. They lived all around Turkey in various cities. A socioeconomic position survey was conducted among parents of children, wherein questions related to their employment, education (primary, secondary, and tertiary), and income were asked. The income categories were defined as follows: low income (< 6,000

TL), middle income (6,000 TL to 20,000 TL), and high income (> 20,000 TL). The participants' occupation was categorized into three groups: staff, blue-collar workers, and white-collar workers.

B. QEEG Recording

In the experiments, EPOC-X headsets are used. The EEG data was read with 2048 per secs per channel -128 per secs per channel down sampled. EEG data were converted to the frequency band data with EMOTIV's standard procedures. The frequency band data is binned as follows: Theta (4-8 Hz), Alpha (8-12 Hz), Beta-1 (12-16 Hz), Beta-2(16-25 Hz), and Gamma (25-45 Hz). The artifacts were removed with a high pass filter (>100 Hz). EMOTIV LAUNCHER is used for the calibration of the headsets, each electrode is soaked well and ensured that EEG data is read with top quality. The recorded channels were AF3, F3, F7, FC5, T7, P7, O1, O2, P8, T8, FC6, F8, F4, and AF4 for EMOTIV EPOC-X.

The EMOTIV EPOC-X, a commercial wearable EEG device, was used for the recordings, which consists of 14 sensors and associated felt pads inserted in the scalp in accordance with the International 10-20 System. As reference channels, two more rubber electrodes were inserted into the mastoids. The connection between the electrodes and the scalp is made using the saline liquid solution that has been administered to all of the felt pads of each sensor, and the sampling frequency is 128 Hz.

C. Neurofeedback Treatment Protocol and Multi-Sensory Learning Method

The Auto Train Brain mobile application employs neurofeedback and multi-sensory learning principles with the EMOTIV EPOC-X headset. This non-invasive approach enhances brain performance in adults and children, devoid of any side effects. The patented software (patent number: PCT/TR2017/050572) is designed to aid individuals with dyslexia by continuously reading QEEG signals from 14 channels, processing them, and delivering real-time visual and auditory online neurofeedback. The system and method for improving reading ability and cognitive functions rely on a unique protocol of multi-sensory learning and EEG neurofeedback. The EEG neurofeedback protocol includes reducing theta waves at the Broca and Wernicke areas in the brain if above the threshold, identifying the channels with the maximum absolute power of theta waves in each hemisphere, and reducing absolute theta for those channels. Positive and negative feedback is provided through green and red arrows on the screen and a "beep" sound. The application also includes a phoneme-grapheme matching alphabet teaching system after the neurofeedback session. Auto Train Brain differs from other neurofeedback systems in that it combines neurofeedback with multi-sensory learning principles.

D. Study Design

There were 40 participants whose ages were between 7-10 years old. All subjects used Auto Train Brain (a mobile phone application) more than 100 times, their brain waves are read using EMOTIV EPOC-X for 14 channels and visual and auditory neurofeedback is given for 30 minutes. After the neurofeedback session, multi-sensory alphabet learning is studied for 15 minutes.

With some assistance from their families at home, the participants completed the 30-minute neurofeedback sessions. Each participant utilized it while seated at a table at home throughout the neurofeedback session. As their parents are told to do in advance, there were 40 centimeters between the subject and the smartphone app. The participants used Auto Train Brain's arrow neurofeedback interface.

At the end of each session, session average data for each frequency band was saved to the database. During the neurofeedback session, sample entropy was calculated for each frequency band data [12].

E. Variance of Sample Entropy for Gamma Band as the Measure

Sample entropy is a complexity measure used to evaluate physiological time-series signals and identify disease states. It is represented by SampEn (m, r, N), which is the negative natural logarithm of the probability that two sets of simultaneous data points of length m and m+1 have distances less than a given tolerance r, given an embedding dimension of m and a number of data points of N.

Variance, on the other hand, is a dispersion measure that represents the expected value of the squared deviation of a random variable from its population or sample means. It reflects how far a set of numbers deviates from their average value.

The sample entropy of the gamma band frequency is calculated and stored for each session. The variance of the gamma band entropies is then calculated for a group of sessions. Normally, sample entropy is calculated based on EEG data series, however, in our calculations, we have used QEEG data as we have not reached raw data from EMOTIV EPOC-X. The feature set consists of 14 variables that contain gamma band values mapped from 14 channels for EMOTIV EPOC-X.

Then the variance of the sample entropy in the gamma band for each group of activities is measured.

F. Statistical Analysis

The statistical analysis was performed with SPSS 22. The regression analysis has been performed and R square values are reported. The increase in the variance of gamma band entropy (y-axis) in the left posterior region in the 100 sessions (x-axis, 1 bin= 10 sessions) was tested for the significance of the regression slope coefficient. It was checked whether our model is a significant predictor of the outcome variable using the results of ANOVA for regression (The change in the variance of gamma band entropy (y-axis) in the left (T7) and right temporal (T8) regions versus session groups (x-axis)).

III. Results

A regression line is drawn (the x coordinate is the session numbers and the y coordinate is the variance of gamma band sample entropy). The findings suggest that long-term neurofeedback use increased the variance of gamma band sample entropy.

The 100 consecutive sessions have been merged into 10 bins. Next, we determined the variance of each bin's gamma band sample entropy. Ten bins were present. We have shown the gamma band sample entropy values' bin number vs variance. In both headsets' left posterior regions, the gamma band sample entropy variance rose over time (T7).

For a 14-channel EEG headset, the regression line yields R^2=0.78 when the first 30 sessions are excluded [$F_{(1, 7)}$ = 15.38, p=.01] (Figure 1). R^2 for the regression line is 0.50 when the first 30 sessions are also included [$F_{(1, 10)}$ = 8.97, p=.01] (Figure 2). In both instances, the linear regression lines' slopes were upward statistically significantly.

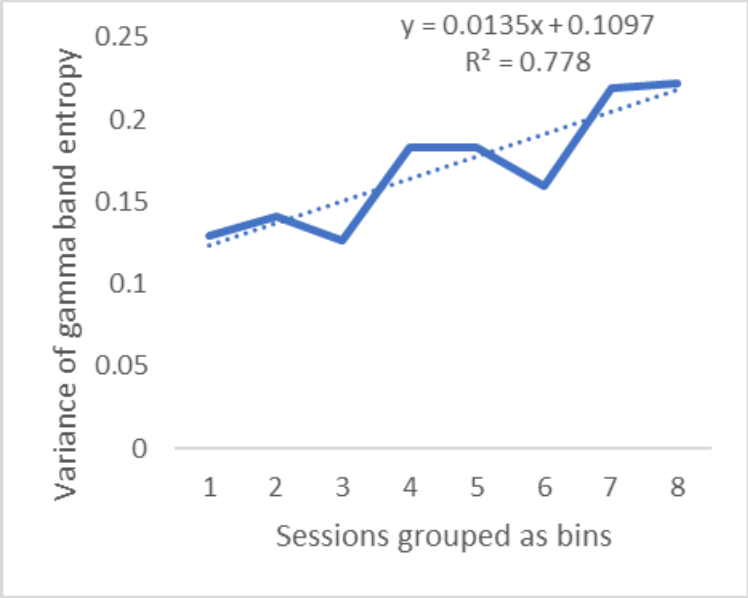

Figure 1.The increase in the variance of gamma band entropy (y-axis) y in the left posterior region after 30 sessions (x-axis, 1 bin=10 sessions) for a 14-channel EEG headset

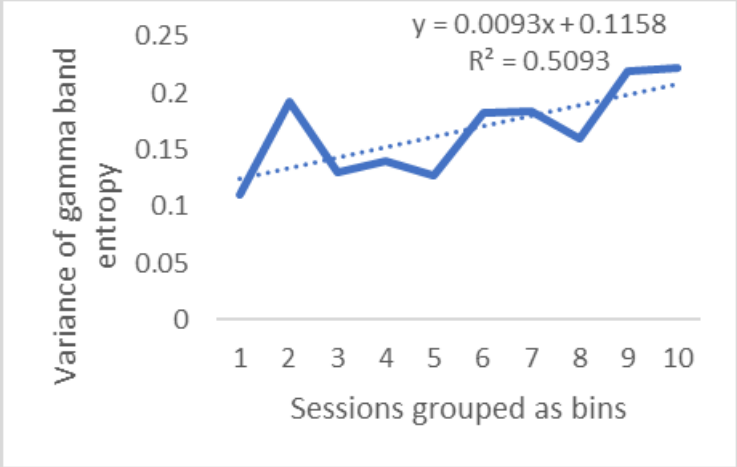

Figure 2. The increase in the variance of gamma band entropy (y-axis) in the left posterior region for a 14-channel EEG headset in the 100 sessions (x-axis, 1 bin= 10 sessions)

For a 14-channel headset, the variance of the gamma band entropy changes in the left temporal and the right temporal regions in the 100 sessions are plotted in Figure 3.

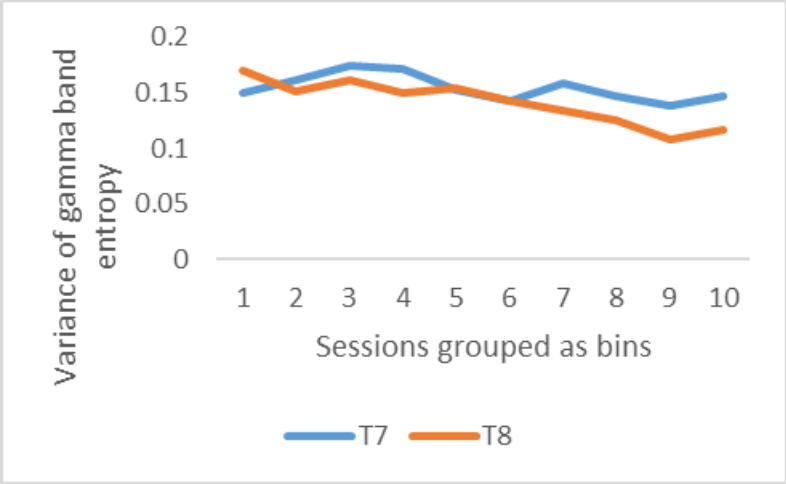

Figure 3. The change in the variance of gamma band entropy (y-axis) in the left (T7) and right temporal (T8) regions for a 14-channel EEG headset in the next 100 sessions (x-axis, 1 bin=10 sessions)

Figure 3 shows that at around 20th sessions, the variance of gamma band entropy becomes permanently dominant for the left temporal region after 60 sessions [$F_{(1, 6)} = 20.79, p=.0038$].

As the participant's ages were 7-10 years old, the result is generalizable to 7-10-year-old children with dyslexia only.

IV. Discussion

This research is unique in its approach to measuring the long-term outcomes of neurofeedback using a novel measurement method. While clinical trials have been conducted to examine the efficacy of neurofeedback on dyslexia, the use of the variance of sample entropy calculated in the gamma band to compare different sessions is a unique approach. Additionally, the focus on the left temporal lobe (T7) compared to the right temporal lobe (T8) is a specific aspect that sets this research apart from previous studies.

In the first 20 sessions of use, 14-channel neurofeedback in the left posterior region causes a sharp increase in the variance of the sample entropy in the gamma band. The variation of the sample entropy in the gamma band is reduced after the 20 sessions for 14-channel neurofeedback with Auto Train Brain, and we assume that the functional networks prune and stabilize after some building and optimization. In the following sessions, there is an increase in the variance of the gamma band entropy. There are two further steps of pruning for both headsets in the remaining sessions. Moreover, the variance of sample entropy in the left temporal lobe becomes dominant after 60 sessions of usage.

A previous clinical study evaluated the effectiveness of Auto Train Brain for children with dyslexia[33], using pre- and post-

TILLS test comparisons. The experimental group showed a significant increase in reading speed from 38 to 65 after the 60-session clinical trial. Additionally, the reading comprehension of the experimental group was significantly improved [$F_{(1, 14)} = 4.98$, p=.042] compared to the control group who received special education. Post-hoc tests showed that Auto Train Brain training resulted in a statistically significant improvement in reading comprehension. The experimental group demonstrated a 70% improvement, progressing from $m = 3.06$ ($SD = 4.22$) to 5.20 ($SD = 4.41$), while the control group exhibited a -10% decline, regressing from $m = 7.12$ ($SD = 3.18$) to $m = 6.36$ ($SD = 4.22$), a -10% improvement[33].

According to Wu's (2022) research, neural stability plays a crucial role in supporting behavioral stability and reading automaticity [35]. Nazari administered neurofeedback to six dyslexic children and noted a normalization of coherence in the theta band at T4-T4, delta band at Cz-Fz, and beta band at Cz-Pz, Cz-Fz, and Cz-C4, despite no significant changes in the power bands. Hypo coherence, indicating a disconnection syndrome, was observed. The author suggests that the significant improvement in reading ability and phonological awareness is attributable to the substantial changes in coherence, indicating the integration of sensory and motor domains. Coherence neurofeedback, as demonstrated by Coben, can raise reading scores by 1.2-grade levels for individuals with reading problems [36]. fMRI has been utilized in the literature to show an increase in functional connectivity after fMRI-based functional connectivity neurofeedback [36]. To evaluate the improved functional connectivity following coherence neurofeedback, the coherence and phase lag on the EEG must be computed. However, real-time coherence calculations using QEEG and EMOTIV headsets are challenging. Therefore, the variance of gamma band entropy across neurofeedback sessions is a suitable indicator of the in-session changes in functional connectivity networks.

The study has several limitations that need to be considered. Firstly, placebo effects could be a factor, as highlighted by [37], where children receiving specialized interventions may exhibit improved functioning simply due to the social and environmental impact of those interventions. Secondly, the experiment spanned over 6 months, which could introduce a maturation effect. Thirdly, the number of participants was limited, given that this was a pilot study, and further research with a larger cohort is warranted. Lastly, the absence of a control group is another limitation of the study.

For future research, we will investigate new calculation methods of coherence and functional connectivity based on QEEG and test our hypotheses with this calculation. The variance of gamma band entropy changes over neurofeedback sessions presents promising results to explain electrophysiological changes and adaptations in the brain. Auto Train Brain was proven to be effective in improving reading comprehension and reading speed beforehand. Now, with the new calculation method, we have investigated the electrophysiological changes in the left temporal region compared with the right temporal region after neurofeedback efficiently.

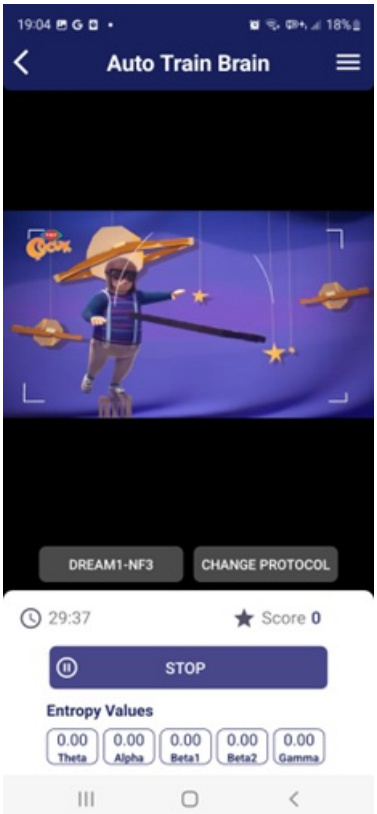

Figure 4. Auto Train Brain "youtube" interface

Acknowledgements

Our experiment's success would not have been possible without the participation of the children with dyslexia and their families. We extend our gratitude to them for their motivation and dedication to the study.

Ethical Approval

All the participants gave their informed consent after the experimental procedure was explained to them by guidelines set by the research ethics committee, the protocol of the study was approved by the Ethics Committee of Yeditepe University and the clinical trial was registered to the Turkey Pharmaceuticals and Medical Devices Agency (Nbr: 71146310-511.06,2.11.2018).

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