

Comparing Live Z-Score Training and Theta/Beta Protocol to Reduce Theta-to-Beta Ratio: A Pilot Study

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Abstract

Objective/Background: Theta-to-Beta ratio is one of the most studied electroencephalography findings in ADHD in the neurotherapy field, alongside the neurofeedback (NF) protocols whose objective is reducing it. The NF field has developed to a great level in the last decade. One of the approaches that became of particular interest to the clinicians has been Z-score training (ZT). In general, there are still a few studies about the efficacy of ZT and even fewer that compare this technique with the classic protocols. This study aimed to check the efficacy of ZT in reducing Theta-to-Beta ratio. **Participants:** 15 patients diagnosed with combined type ADHD aged 7 to 18, recruited in retrospect. **Methods:** The participants were divided in two groups. One of the groups was provided with the ZT intervention and the other one, the Theta/Beta (T/B) protocol. Both groups went through ten 30-min NF sessions using videos selected by themselves as a reinforcement. The main outcomes of this study were the patients' Theta-to-Beta ratio metrics. **Results:** Both groups showed a decrease in Theta-to-Beta ratio; the ZT group showed a decrease of 1.02 points average and the T/B group showed a decrease of 0.15 points average, only being statistically significant for the ZT group.

Keywords: neurofeedback; Z-score training; Theta-to-Beta ratio

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Introduction

Biofeedback (BF) is an applied field within psychophysiology. Neurofeedback (NF), which is a subdivision of BF, is focused on controlling the electroencephalographic (EEG) activity (Carrobes, 2016). NF is based on the operant conditioning (i.e., behavior modification by rewards and punishments) application to the EEG activity (Monastra, Monastra, & George, 2002). The EEG activity is recorded by a device (amplifier) and processed with specialized software that allows it to break down the EEG into frequency bands (Delta, Theta, Alpha, Beta, etc.), and also to measure the average voltage or the

amplitude of each band at a certain point (Carrobes, 2016; Demos, 2005).

In classical NF, also known as power training, it is possible to reinforce, inhibit, or ignore the different bands. For the bands that are being reinforced, an amplitude threshold is established that must be exceeded to obtain feedback. For the bands that are being inhibited, a threshold is established, and the amplitudes must remain under it in order to obtain reinforcement. When there is more than one frequency band being reinforced and/or inhibited, all set thresholds must be within the set range to receive feedback (Demos, 2005). This feedback—which can be visual (e.g., films), auditory (e.g., music), vibratory,

or mixed—is contingent on the fulfillment of the thresholds for each band present in the EEG.

Throughout the years, there have been a number of protocols within the context of the NF power training which are nowadays considered by the literature as classical protocols. Ever since the Monastra et al. (1999; Monastra, Lubar, & Linden, 2001) studies showed that the finding of a Theta-to-Beta ratio could be a possible indicator of attention-deficit/hyperactivity disorder (ADHD), there began to emerge a great number of studies that used the Theta/Beta (T/B) protocol as a possible intervention in ADHD cases (Arns, de Ridder, Strehl, Breteler, & Coenen, 2009; Bakhshayesh, Hänsch, Wyschkon, Rezai, & Esser, 2011; Leins et al., 2007). Among those classical protocols, we find the T/B applied in general to Cz (one of the International 10/20 system locations) that inhibits Theta-to-Beta ratio, which essentially means inhibiting the Theta activity and enhancing the Beta activity at the sensorimotor cortex (Monastra et al., 2005; Rossiter, 2002). When the patient meets the criteria, he subsequently receives the reinforcement (Monastra et al., 2005; Rossiter & La Vaque, 1995).

Even though this protocol was first used to treat the ADHD, it has also been applied as a one-size-fits-all protocol for other conditions such as insomnia (Hammer, Colbert, Brown, & Ilioi, 2011; Schabus et al., 2014), cognitive performance (Doppelmayer & Weber, 2011), impulsivity (Bluschke, Broschwitz, Khol, Roessner, & Beste, 2016; Liu, Hou, Sourina, & Bazanova, 2016), and executive functions or autism (Kouijzer, de Moor, Gerrits, Congedo, & van Schie, 2009).

In recent years, technological advances have allowed new possibilities to be created in the field of NF (Hammer et al., 2011) through different paradigms: amplitude neurofeedback, Z-score-based neurofeedback, infralow frequency neurofeedback, infralow fluctuation neurofeedback, or low resolution electromagnetic tomography analysis (LORETA)-based neurofeedback.

Since its inception at the beginning of the 2000s (Collura, 2008, 2014), Z-score training (ZT) has attracted interest among the NF scientific community resulting in several case (Collura, Guan, Tarrant, Bailey, & Starr, 2010; Koberda, Moses, Koberda, & Koberda, 2012; Pérez-Elvira, Carrobbles, López Bote, & Oltra-Cucarella, 2019; Pérez-Elvira et al., 2018; Smith, 2008) and group studies (Groeneveld et al., 2019; Hammer et al., 2011; Krigbaum & Wigton, 2015; Wigton, 2014; Wigton & Krigbaum, 2015). In

ZT all the patients' EEG Z-scores from all elements (absolute power, relative power, coherence, etc.) are computed and collected at all times, the percentage of Z-scores within a specific range (for instance, ± 1 SD) is calculated, and the patient receives feedback every time the percentage of Z-scores within the normal range is equal to or higher than a requested percentage.

ZT has shown efficacy in different pathologies such as ADHD, epilepsy, migraine, depression, anxiety, insomnia, and learning disorders (Guan, 2016; Hammer et al., 2011; Pérez-Elvira et al., 2019; Walker, 2016). In fact, there are some authors, such as Lubar (2015), who indicate that NF based on Z-score promotes faster learning than classical NF. This has also been partly verified by the Wigton and Krigbaum studies (Krigbaum & Wigton, 2015; Wigton & Krigbaum, 2015) that presented a normalization of the EEG in approximately 10 sessions, against the average 40 necessary in the classical NF, (Krigbaum & Wigton, 2014; Thatcher, 2013; Wigton, 2013; Wigton & Krigbaum, 2015) or even more than 60 in some cases (Sürmeli & Ertem, 2011; Sürmeli, Erthem, Eralp, & Kos, 2012).

The aim of this investigation was to study ZT's capacity to reduce Theta-to-Beta ratio while comparing that intervention with an active control group who followed a T/B protocol.

Methods

Subjects

A total of 15 subjects, 12 boys and 3 girls from NEPSA Rehabilitación Neurológica (a Neurorehabilitation Clinic) who went looking for NF treatment, took part in this study, which has a gender ratio of 4:1 to represent the ratio of boys to girls usually found in ADHD. Their data were retrospectively analyzed. The inclusion criteria were:

- 1) being diagnosed with combined type ADHD by a school psychologist, a neurologist, and/or neuropsychiatrist,
- 2) being between the ages of 7 and 18 ($M = 12$, $SD = 3.5$, range = 7–18),
- 3) having a Theta-to-Beta ratio higher than what is to be expected for that age range (Demos, 2019),
- 4) not taking any medication, and
- 5) having completed 10 NF sessions between September and December 2018.

Moreover, all of the subjects took an intelligence test (Wechsler Intelligence Scale for Children – Fourth

Edition [WISC-IV] or Wechsler Abbreviated Scale of Intelligence – Second Edition [WASI-II]) and scored within the normal range.

The subjects or the subjects' parents signed an informed consent to apply the treatment on them and for the subsequent anonymized use of their data for researching purposes. The intervention took place at NEPSA Rehabilitación Neurológica, a neurological rehabilitation clinic authorized by the Health Department of the Autonomous Community of Castile-Leon (Spain). The Health Department granted approval for psychophysiological interventions of this kind within the context of psychological treatments.

Instruments and Procedure

Quantitative EEG Recording and Analysis

A quantitative EEG (qEEG) was recorded before starting the NF intervention and after 10 NF sessions. To record the EEG, the subjects were fitted with a 19-channel Free-cap (Institute for EEG-Neurofeedback [IFEN], Baldham, Germany) according to the International 10/20 system with Linked Ears montage (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, and O2). For 3 min, the EEG signals were obtained and collected simultaneously over those 19 channels with a Discovery20 amplifier (BrainMaster Technologies, Inc., Bedford, OH). The EEG recordings were recorded in an eyes-open condition, using BrainAvatar 4.6.4 (BrainMaster Technologies, Bedford, OH).

The EEG signals were imported into the Analyzer of BrainAvatar 4.6.4, a software for computation and analysis, where artefacts (i.e., activity collected from the EEG that was not produced by the brain) were visually inspected and removed. The EEG was processed with Linked Ears Montage, and Theta-to-Beta ratio values were obtained for each participant. The Theta and Beta ranges were 4–8 Hz and 13–21 Hz, respectively (Demos, 2019).

It was explained to each participant or to their parents how the different treatments (T/B and ZT) worked according to the scientific data available at that moment, and they chose which one to follow. The final layout for the treatments was that nine subjects followed the T/B and six followed the ZT.

Neurofeedback

Theta/Beta Protocol Group

This group received a 30-min session twice a week in which the T/B protocol in Cz was applied with a total of 10 sessions. The sessions entailed inhibiting the Theta band, enhancing Beta, and inhibiting HiBeta. In our study, HiBeta range was 21–30 Hz. Short videos selected by the subjects were used to produce the feedback. A dimmer was placed in front of the video screen which brightened up when the patient met the criteria of the protocol (Theta and HiBeta below the selected threshold, and Beta above the selected threshold) or became opaque, preventing the video from being viewed, when the criteria were not met.

Z-scores Training Neurofeedback Group

This group followed the Brain Avatar's ZT PZOKUL protocol (BrainMaster Technologies, Inc., Bedford, OH) twice a week during a 30-min session with a total of 10 sessions. The locations F3, F4, P3, and P4 were selected since this combination of locations in ZT protocols has been suggested to regulate whole head EEG activity (Collura, 2008). This protocol has a training threshold that auto-adjusts based on the percentage of Z-scores within the upper and lower selected limits. We used a one standard deviation as the upper and lower thresholds following the indications of some authors (Thatcher & Lubar, 2015). Short videos selected by the subjects were used to produce the feedback. A dimmer was placed in front of the video screen which brightened up when the patient met the criteria or became opaque, preventing the video from being viewed, when the criteria were not met.

Statistical Analysis

The data were analyzed using version 25 SPSS software. Since our sample was small and heterogeneous, Mann-Whitney-U and Wilcoxon signed-rank test analyses were utilized. Statistical significance was set at $\alpha = 0.05$ for all analyses. Cohen's d effect size was also calculated to assess the magnitude of the observed changes.

Results

Our sample was composed of 15 subjects with ADHD, 12 boys and 3 girls, which corresponds to the common 4:1 ratio in this disorder. There were six subjects in the ZT group and nine subjects in the T/B group. Theta-to-Beta ratios were calculated for each subject and group at Cz location. Those results can be found in Table 1. Both groups showed no significant differences regarding age ($U = 19.50$, $p =$

.390), and there were no significant differences in the pretreatment Theta-to-Beta ratio between the groups ($U = 24, p = .723$).

Table 1
Age and pretreatment and posttreatment T/B ratios at Cz

| | ZT Group | | T/B Group | |
|----------------|----------|------|-----------|------|
| | M | SD | M | SD |
| Age | 11.17 | 3.97 | 12.56 | 3.28 |
| Pre T/B ratio | 2.63 | 0.11 | 2.62 | 0.21 |
| Post T/B ratio | 1.61 | 0.32 | 2.47 | 0.17 |

After 10 treatment sessions, both groups presented a decrease of Theta-to-Beta ratio (Figure 1). The ZT group showed an average difference of 1.02 points, which was statistically significant ($W = -2.20, p = .02$) and the T/B group showed an average difference of 0.15 points, which was not significant ($W = -1.48, p = .110$). Theta-to-Beta ratio's difference between both groups following the intervention was statistically significant ($U = 5, p = .009$). The Cohen's d analysis found a large effect of group type ($d = 1.39$).

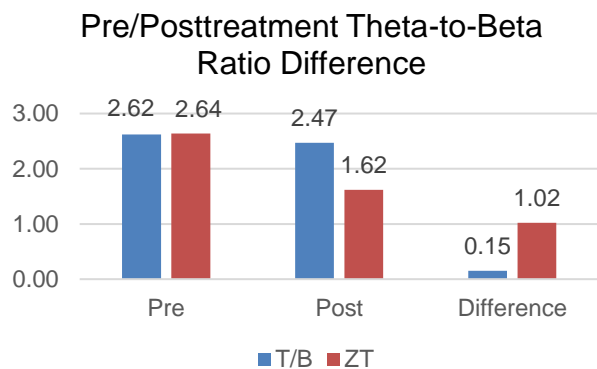


Figure 1. Theta-to-Beta Ratio, at Cz, for each group preneurofeedback (pre), postneurofeedback (post) and difference pre–post (difference). The Theta and Beta ranges were 4–8 Hz and 13–21 Hz, respectively.

Discussion

This retrospective study aimed to analyze the efficacy of a ZT intervention to regulate Theta-to-Beta ratio in a combined type ADHD sample. According to our

findings, ZT is probably an effective way to regulate Theta-to-Beta ratio. Only 10 sessions created a large and statistically significant change in the desired direction. In addition, it had a bigger impact than the active control condition (T/B protocol) which did not produce a significant change after 10 sessions.

Even though the T/B has shown its efficacy in reducing Theta-to-Beta ratio (Janssen et al., 2017) and in our study it also created changes in the desired direction, they were not significant. One reason could be the fact that it usually takes the power classical protocols up to 40 sessions or more to produce a significant effect (Bell, Moss, & Kallmeyer, 2019; Krigbaum & Wigton, 2014; Sürmeli & Ertem, 2011; Sürmeli et al., 2012; Thatcher, 2013; Wigton, 2013; Wigton & Krigbaum, 2015).

On the other hand, our results are consistent with previous studies about ZT, in which there were relevant results in a few sessions (Bell et al., 2019; Pérez-Elvira et al., 2019; Wigton & Krigbaum, 2015). Wigton and Krigbaum (2015), and Krigbaum and Wigton (2015), developed a method to monitor the progression of the ZT treatment and observed a normalization of the patients' EEG in approximately 10 intervention sessions. In the same vein, Groeneveld et al. (2019), following Krigbaum and Wigton's monitoring method (2015), found a normalization of the EEG in an average 30 ZT sessions. Pérez-Elvira et al. (2019) reached the normalization of the EEG of a patient with insomnia in 30 ZT sessions.

A possible reason for the ZT's superiority over the T/B protocol, at least regarding the number of sessions that are needed on each one, could be that amplitude NF allows to control a small number of factors at the same time (Soutar & Longo, 2011). However, ZT could simultaneously train up to 248 Z-scores (with 4 EEG channels) at the same time (Collura et al., 2010; Gracefire, 2016).

Even though there are enough studies that compare the use of NF, mostly its classical protocols, with other treatments, such as cognitive behavioral therapy (Moreno-García, Delgado-Pardo, Camacho-Vara de Rey, Meneres-Sancho, & Servera-Barceló, 2015; Moreno-García, Meneres-Sancho, Camacho-Vara de Rey, & Servera, 2019; Schöenberg et al., 2017), pharmacological (Bioulac et al., 2019; González-Castro, Cueli, Rodríguez, García, & Álvarez, 2016; Meisel, Servera, Garcia-Banda, Cardo, & Moreno, 2014; Moreno-García et al., 2015, 2019; Razoki, 2018; Rossiter & La Vaque, 1995; Yan, Zhang, Yuan, & Cortese, 2018), there was only one prior study

(Hammer et al., 2011) that had compared the efficacy of ZT with the one of a classical protocol. Hammer et al. (2011) found in their study improvements in sleep quality after 10 ZT sessions in people with insomnia. But, in contrast to Hammer et al. (2011) who used a classical sensorimotor modified protocol combined with ZT, we used as active control a group who followed the classical T/B protocol.

This study had several obvious limitations; the most important ones being the small size of the sample and the lack of follow-up. Another limitation was the fact that the study was aimed at both treatment methodologies (ZT and T/B) without explicitly considering the clinical variables, aside from the ADHD diagnosis, and thus there were no psychometric measures included. However, the study has provided certain evidence about the efficacy and the speed in reducing high Theta-to-Beta ratio, thus offering a foundation to study the same effect in future and more controlled investigations.

Moreover, the study has included effect size metrics, making it a candidate to be included in future meta-analysis. In conclusion, ZT seems to be a good and quick approach to reduce Theta-to-Beta ratio in ADHD patients.

Author Disclosure

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