Research Paper

Comparing Theta Beta Ratio in Children With Attention-deficit/hyperactive Disorder and Specific Learning Disorder During Active EEG

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ABSTRACT

Introduction: Theta-to-beta ratio (TBR) has been claimed as a biomarker to diagnose attention-deficit/hyperactivity disorder (ADHD). However, the effectiveness of this index in identifying different groups of ADHD is still under discussion. Our primary purpose was to determine to what extent active TBR can differentiate between children with ADHD and specific learning disorder (SLD) as the most common comorbid disorder.

Methods: Two groups of school-aged children with SLD (n=15) and ADHD (n=15) were diagnosed through a process of clinical interview and observation. Electroencephalography (EEG) was recorded in both groups during active conditions. The implemented cognitive task was the visual continuous performance task (VCPT). TBR in sites of CZ and Fz and cognitive measures of VCPT were calculated in the study groups.

Results: There were no significant differences in cognitive measures (commission, omission, reaction time, and variability of reaction times) shown in two matched groups of children with SLD and ADHD. According to TBR, the two groups demonstrated no significant differences in comparison.

Conclusion: TBR cannot be considered a reliable biomarker to differentiate between those groups of psychological disorders that contain primary cognitive deficits and require the allocation of attention and working memory loads.

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Highlights

● There is no significant difference in theta-beta ratio at frontocentral electrodes between children with attention-deficit/hyperactivity disorder (ADHD) and learning disorder (SLD).

● There is no significant difference between children with ADHD and SLD in reaction time, omission errors, or commission errors in a visual continuous performance task.

● The theta-to-beta ratio is not a reliable marker for differentiating ADHD from SLD in children.

Plain Language Summary

ADHD and SLD are common childhood conditions that affect attention, impulse control, and academic performance. Since these disorders often overlap, researchers have been exploring ways to differentiate them using brain activity measurements, such as electroencephalography (EEG). One commonly studied biomarker in ADHD is the theta-to-beta ratio. However, it remains unclear whether it can effectively distinguish ADHD from SLD. In this study, we examined brain activity in two groups of children with ADHD and SLD during a computerized attention task. The EEG recording focused on the theta-to-beta ratio at key areas of the brain involved in attention and self-control. We also compared their response times and errors during the task. The results showed no significant differences in the theta-to-beta ratio between children with ADHD and SLD. Additionally, both groups had similar performance in the attention task, with no notable differences in reaction time, omission errors (missed responses), or commission errors (incorrect responses). These findings suggest that theta-to-beta ratio is not a reliable marker for distinguishing between ADHD and SLD. This highlights the need for more precise tools to differentiate these disorders, ensuring that children receive appropriate interventions tailored to their specific needs.

1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is one of the most prevalent chronic childhood mental illnesses, affecting 4%-12% of all school-aged children and persisting in roughly 66%-85% of cases (Getahun et al., 2013). The disease affects individuals across the lifespan (Sonuga-Barke et al., 2013). It is characterized by age-inappropriate, chronic, and pervasive symptoms of inattention, hyperactivity, and or impulsivity. These symptoms are associated with a high risk of scholastic failure, interpersonal difficulties, and mental illnesses (Sonuga-Barke et al., 2013).

Electroencephalography (EEG) measurements show the relationship between intracranial electrical currents and the scalp's resultant voltages, representing specific aspects of brain electrical activity and processing. Many pieces of research have been conducted to compare brain activity in children with ADHD to normal controls, particularly utilizing EEG, to shed more light on the underlying neurophysiology of ADHD and to study subtypes of ADHD with varied responses to treatment (Arns et al., 2013). The most commonly reported EEG characteristics associated with ADHD are increased slow wave power (delta, theta) and or decreased fast wave power (beta), which are occasionally combined and indexed as theta-to-beta ratio (TBR): The ratio of theta band (4-7 Hz) power divided by beta band (13-30 Hz) power (Arns et al., 2013; Lenartowicz & Loo, 2014; Barry et al., 2003). Previous studies that employed TBR to distinguish an ADHD group from a control group found a sensitivity of 87% and a specificity of 94% (Snyder & Hall, 2006).

A significant increase in power in the theta band might be used to establish an ADHD diagnosis. In ADHD, elevated theta might be regarded as a sign of inattention and executive dysfunction (Ogrim et al., 2012). However, the diagnostic value of the TBR biomarker increases when it can make a differentiation between ADHD and other disorders (especially other neurodevelopmental dysfunctions). Nevertheless, very little research has been done on the discriminative power of the TBR index for psychological disorders. Cooldige et al. (2007) investigated the differential power of TBR among children with different psychological problems and found its lack of power both in terms of sensitivity and specificity to diagnose children with ADHD.

This issue is especially critical in children with learning disabilities (LD). Previous research has indicated high comorbidity for ADHD and LD in children. That is, attention deficit hyperactivity disorder has the highest comorbidity rate with learning disorder, co-occurs 33% to 45% of the time with reading disability and 11% of the time with mathematical disability (Mayes et al., 2000; DuPaul et al., 2013; Butterworth & Kova, 2013). The rate is so high that it has led Hendrickson et al. (2007) to consider attention impairments as one of the subgroups of learning disorders, along with verbal and non-verbal types.

On the other hand, a wide range of EEG studies have shown greater theta and less beta power in frontal areas in children with LD compared to the control group (Jäncke et al., 2019). In their research on LD children, Jäncke and Alahamadi (2016) found that theta/beta and theta/alpha ratios were much higher in LD children than in healthy children, indicating a significant slowdown of EEG oscillations, particularly for frontal scalp positions (involved in the control of executive functions, attention, planning, and language). Moreover, in a review of the studies that considered or disregarded ADHD comorbidity, Chabot et al. (2001) indicated that in addition to alpha and theta deviations, an elevated ratio of theta to beta has been shown in children with learning disabilities. Chabot concluded that due to the overlap of behavioral symptoms and common neural infrastructure, attention deficit might be considered one of the LD subgroups (Chabot et al., 2001).

In the present study, the power of the TBR biomarker to differentiate between ADHD and LD was investigated during the cognitive task condition.

2. Materials and Methods

Study subjects

In this descriptive causal-comparative study, we examined 2 different groups of children: 15 children who met the criteria for specific learning disorder (SLD) according to DSM-5 (4 girls and 11 boys, Mean±SD age: 8.8±1.14 y) and 15 children who met the criteria for ADHD according to DSM-5 (3 girls and 12 boys, Mean±SD age: 8.9±SD y). The sample was collected from students with complaints of difficulty in academic achievements who were referred to the Atieh Clinical Neuroscience Center (Tehran City, Iran) from July to November 2020.

A clinical psychologist, an educational psychologist, and a psychiatrist checked the criteria with parents during psychological interviews and observed the child in separate sessions. Subjects who received a joint diagnosis from all three specialists were included in the study. The subjects were matched in two groups based on age. Normal intelligence ability was tested earlier in children with SLD diagnosis by the revised version of the Tehran-Stanford-Binet intelligence scale (Mahvashe et al., 2014). The exclusion criteria were a history of neurological and or psychiatric problems, severe sociocultural disadvantages, abnormal psychomotor development, and visual and auditory deficits. Excluded children with anxiety, mood, or other psychiatric disorders received the diagnosis through the interview process. Furthermore, all three presentations of ADHD were included in the study.

Visual continuous performance task (VCPT)

This study used a VCPT. This task was a cued go/no-go task and primarily assessed the executive function of suppressing an action. The 400 trials were divided into four categories, each consisting of a pair of sequentially presented visual stimuli. In go trials, a picture of an animal is followed by a picture of an animal, and the participant is asked to press a button as fast as possible. In no-go trials, the participant is asked to refrain from clicking the button since a picture of an animal is followed by a picture of a plant. No action is needed in ignore trials. In this condition, a picture of a plant is followed by a picture of a plant or a human (in the novelty condition, a picture of a plant is followed by a picture of a human being, the latter being presented along with a novel sound) (Mueller et al., 2010). VCPT was presented via open-source Python software and synchronized with EEG Studio software to record electroencephalograph data.

Electroencephalographic Recording

Electroencephalograms were recorded using the 19-channel Mitsar-EEG system (Mitsar, Russia) in an active (VCPT task) state. We used 19 silver-chloride electrodes fixed to the scalp according to the international 10-20 system using Electro-Cap (ElectroCap, Inc, OH) with its electrodes placed on Fp1/Fp2, F3/F4, C3/C4, P3/P4, O1/O2, F7/F8, T3/T4, T5, T6, Fz, Cz, and Pz. The EEG input signals were referenced to linked ears, filtered between 0.5 to 40 Hz, and digitized at a rate of 500 Hz. The ground electrode was placed on the forehead. All electrode impedances were kept below 5 kΩ. EEG was recorded for at least 22 minutes during the VCPT task. The participants were sat in a comfortable chair in a dimly lit, acoustically isolated room. The participants were instructed to sit still without blinking or moving their eyes. WinEEG software was used to correct and preprocess artifacts. Artifact-contaminated epochs (eye blinks, rapid eye movements, slow head or body movements, and myographic artifacts) were automatically marked and excluded from further analysis. The exclusion thresholds were set as follows: (a) 100 µV for nonfiltered EEG, (b) 50 µV for slow waves in the 0–1 Hz band, and (c) 20 µV for fast waves filtered in the 20–35 Hz band. For EEG data analysis, not less than 30 artifact-free EEG epochs were used (around 60 s).

Data analysis

WinEEG software, was used for artifact correction and preprocessing. Artifact-contaminated epochs (eye blinks, rapid eye movements, slow head or body movements, and myographic artifacts) were automatically marked and excluded from further analysis. The exclusion thresholds were set as follows: (a) 100 µV for nonfiltered EEG, (b) 50 µV for slow waves in the 0–1 Hz band, and (c) 20 µV for fast waves filtered in the 20–35 Hz band. For EEG data analysis, not less than 30 artifact-free EEG epochs were used (around 60 s).

After applying the quick Fourier transform, the absolute power was computed for the theta (4–8 Hz) and beta1 (13–20 Hz) frequency bands in Fz and Cz. The TBR was computed in these regions, and the t-test was used to compare the groups' mean. It should be mentioned that to get close to the normal distribution, we applied an independent t-test after calculating the logarithms for the amplitude numbers.

3. Results

Table 1 presents the demographic characteristics of the participants. The participants' ages ranged from 7 to 10 years. The chi-square test was performed to compare age and gender groupings. The chi-square test revealed no significant differences ($P<0.05$) between the groups regarding age and gender variables, as shown in Table 1. Therefore, it can be argued that both groups of SLD and ADHD were matched in age and gender characteristics.

We compared the group's performance in the VCPT task based on omission ($t=0.021$), commission ($t=0.292$), reaction time ($t=-1.281$), and variance in responses ($t=1.091$). Table 2 shows no significant difference between the two groups regarding behavioral variables ($P<0.05$).

Based on Table 3, the results of the independent t-test indicated no significant difference between the groups regarding TBR in Fz ($t=-0.492$, $P=0.62$) and Cz ($t=0.406$, P value=0.68) during the VCPT condition ($P<0.05$). Therefore, no significant difference was found between SLD and ADHD children in terms of TBR in Cz and Fz sites during the VCPT task.

4. Discussion

In this study, TBR during a visual CPT was investigated in children with ADHD compared to children with SLD. EEG data were recorded on frontal and central sites. In addition, differences in the performance of these groups in VCPT were also calculated. Our analysis revealed significant distinctions in TBR and cognitive measures of CPT.

The ADHD group, compared to SLD, presented no difference in central and frontal TBR during attention tasks. There is no literature comparing the TBR of these groups while doing a cognitive performance task. However, the controversial issues of TBR differentiation power for people with LD and especially ADHD are still ongoing. Many studies have shown increased TBR or elevated slow waves in individuals with ADHD (e.g. Markovska-Simoska & Pop-Jordanova, 2017; Fonseca et al., 2008; Ogrim et al., 2012; Boutros et al., 2005; Chabot et al. 2001; Monastra et al., 2001) and learning disabilities (e.g. Jäncke et al., 2017; Jäncke & Alhamadi, 2016; Fernandez et al., 2003; Chabot et al. 2001). For example, Markovska-Simoska et al. (2017) reported 81% accuracy in the differentiation of unmedicated ADHD individuals from healthy controls using TBR power. Although TBR abnormalities have typically been found in ADHD populations, several studies failed to replicate the differences (e.g. Saad et al., 2015; Poil et al., 2014; Arns & Gordon, 2014; Arns et al., 2013; Barry et al., 2009; Murias et al., 2007).

Even if the TBR power to differentiate between ADHD and HC is assumed reliable, it might not be an effective biomarker unless it also differentiates ADHD from other mental conditions (especially neurodevelopmental disorders). In a leading investigation by Coolidge et al., QEEG was used as a diagnostic tool in children with different emotional and behavioral problems. Using TBR to diagnose ADHD among children with a vast range of psychological issues, Coolidge et al. (2007) found a sensitivity of 50% and a specificity of 36%, differentiating ADHD (as estimated by parents) from other psychological disorders. In the current study, differentiation and sensitivity/specificity measures were not calculated, but the results are consistent with the aforementioned study, showing that TBR inefficiency should be counted for differentiating ADHD from other mental health issues.

Table 1. Demographic characteristics

Variables		No. (%)		χ^2	P
		ADHD (n=15)	SLD (n=15)		
Age (y)	7	2(40)	3(60)	1.45	0.69
	8	4(66.7)	2(33.3)		
	9	3(37.5)	5(62.5)		
	10	6(54.5)	5(45.5)		
Gender	Girl	3(42.9)	4(57.1)	0.18	0.67
	Boy	12(52.2)	11(47.8)		

ADHD: Attention-deficit/hyperactivity disorder; SLD: Specific learning disorder.

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Table 2. Comparing behavioral parameters during VCPT task

Performance	Mean±SD		t	df	P
	ADHD	SLD			
Omission	13.66±12.151	13.53±20.982	0.021	28	0.98
Commission	2.2±2.833	1.93±2.12	0.292	28	0.77
RT (ms)	426.89±240.585	520±146.257	-1.281	28	0.21
VR	21.5±6.31	18.74±7.46	1.091	28	0.28

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Abbreviations: ADHD: Attention-deficit/hyperactivity disorder; VCPT: Visual continuous performance task; VR: Variance in responses; RT: Reaction time; SLD: Specific learning disorder.

In most studies on this matter, the conventional, most regular approach of QEEG research (i.e. eyes-open or eyes-closed resting condition) (Klimesch, 1999) has been used. In this approach, we can examine the brain's baseline (tonic) features in a resting state. By comparison, only scarce literature exists on QEEG under active conditions, mainly focused on brain dynamics while doing a task using an even-related (phasic) paradigm. P300 amplitude and latency in attention tasks (such as oddball, CPT, and go/no-go) are reported as a standard component to study aspects of processing in ADHD literature (e.g. Barry et al., 2003; Fallagater et al., 2004; Clarke et al., 2019) and to compare information processing and inhibition in individuals with ADHD and LD (e.g. Lubar et al., 1990; Buchman et al., 2011). Jonkman et al. (2000) came with reduced P300 amplitude to target stimuli in children with ADHD, while in new stimuli, P300 was normal. They claimed that it shows a deficit in attention

Table 3. TBR comparison between groups during VCPT task in Cz and Fz

Electrodes	Mean±SD		t	df	P
	ADHD	SLD			
FZ	5.45±2.247	5.99±3.680	-0.492	28	0.62
CZ	7.29±3.086	6.58±2.784	0.406	28	0.68

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Abbreviations: ADHD: Attention-deficit/hyperactivity disorder; VCPT: Visual continuous performance task; SLD: Specific learning disorder.

allocation but not poorer cerebral processing capacity. On the other hand, tonic arousal, as presented by frontal TBR, is shown to be increased rather than phasic arousal (i.e. P300 component) in various attention tasks in healthy subjects (Howell et al., 2010). Our current research investigated TBR in ADHD and LD as a tonic arousal index in frontocentral areas during a task that requires both inhibition and attention allocation. Accordingly, though there was no difference in TBR in children with ADHD and LD during the task, there might still be distinctive TBR in the ADHD group in the default mode resting state. Several studies show that latency and amplitude in P300 might be a more effective biomarker index for investigating hypothetical differences between these disorders while doing cognitive tasks.

On the other hand, main executive functions have long been associated with the frontal cortex (Fiske & Holmboe, 2019). Many studies have acknowledged mid-frontal TBR as a marker for cognitive functions rather than the brain arousal index. According to the findings, theta oscillation might be related both to inhibitory control (Angelidis et al., 2018; Cavanagh & Frank, 2014; Putamen et al., 2014), attention (Guo et al., 2020; Onton et al., 2005), and processing speed (Zhang et al., 2017).

In a series of studies, (Barry et al., 2004, Barry et al., 2005, Barry et al., 2009) found no link between TBR and skin conductance level as a widely acceptable measure of arousal. Clarke et al. (2019) investigated the association between TBR and amplitude and latency of the P300 ERP component during an attentional task, showing TBR as linked with cognitive capacity in the normal group. Accumulating evidence on individuals with ADHD (Gou et al., 2020; Picken et al., 2020; Halawa et al., 2017; Markovska-Simoska & Pop-Jordanova, 2017; van Dongen-Boomsma et al., 2010) also confirms that frontal TBR is related to executive, most notably attentional, control. Given the nearly consistent results in the role of TBR in cognitive control, an elevated TBR index during cognitive performance tasks in groups with cognitive impairments is reasonably expected. Training cognitive abilities might decrease the index during rehabilitation, as Sari et al. (2015) have found about anxious people with executive dysfunctions.

In our findings, in line with QEEG results, no differences in attention, inhibitory control, and processing speed were found between the groups with LD and ADHD. Complying with our findings, many studies are showing executive dysfunctions in individuals with ADHD and SLD. As Barkley (1997) suggested, ADHD is claimed to emerge from a primary deficit in executive functions with a specific core of dysfunctional response inhibition, which has been investigated in several diagnostic and therapeutic studies (e.g. Baumeister et al., 2018; Azami et al., 2016; Buchmann, 2011; Martinussen et al., 2005; Cornoldi et al., 2001; Mariani & Barkley, 1997). Other investigations have shown the importance of inhibition and attention impairments associated with mathematics and reading underachievement (Cartwright et al., 2012; Merrell & Tymms, 2001). Executive functions in people with pure ADHD, pure LD, and combined LD+ADHD have been compared in several research, mostly seen similar difficulties in inhibitory control (Abou El Wafa et al., 2020; Ghamarigivi et al., 2009; Passolunghi et al., 2005) and regulation of attention resources (Martinussen & Tannock, 2006, Wu et al., 2002), while more severe impairment was observed in children with comorbidity (Purvis & Tannock, 2000; Huang et al., 2016).

5. Conclusion

Considering the findings, observing similar cerebral activations in frontocentral areas in these groups during a cognitive task may confirm the role of theta/beta oscillations in attention and inhibition.

Study Limitations

This study has a number of restrictions. The medication usage in subjects was not controlled, and we have no data that would determine if there was a difference between unmedicated vs medicated children. Resting state EEG and cognitive tasks in active conditions may demonstrate greater accuracy in identifying ADHD and LD. Also, including a larger sample size will result in more convincing results, especially with age considerations to contemplate maturational delay. These are challenges for future research.

Ethical Considerations

Compliance with ethical guidelines

All procedures were in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration revised in 2008. Informed consent was obtained from legally authorized representatives (parents) of all subjects to be included in the study.

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Authors' contributions

Data collection and data analysis: Fatemeh Gholamali Nezhad: Writing the original draft: Fatemeh Gholamali Nezhad and Mahdieh Sadat Mirmohammad and Hanieh Ahmadi; Review and editing: Mahdieh Sadat Mirmohammad: Supervision: Reza Rostami.

Conflict of interest

All authors declared no conflict of interest.

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